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Volume I: Sink Factors

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16. ABSTRACT

Sink and emission factors, standardized where possible, into SI units of micrograms per square meter of surface area per hour ($\mu g\ m^{-2}\ hr^{-1}$) are reported based on an extensive English and foreign language literature search. Approximately 2,000 English abstracts are listed derived from English, German, Russian, Japanese and other source literature. Data is reported relative to the removal of ammonia, carbon monoxide, chlorine, fluorine, hydrocarbons, nitrogen oxides, peroxyacetylnitrate(PAN) particulates, and sulfur dioxide, by vegetation, soil and water. Emission of ammonia, carbon monoxide, hydrocarbons and nitrogen oxides are also reported to the extent that they are found in the literature.

The level of confidence placed on the data is briefly described and the overall conclusions, which can be made based on these data, are presented. Volume I is a complement to Volumes II and III which form part of this project.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Plants Trees Recreation Areas Forests Soils Natural Emission Sources Urban Areas Residential Areas	Open Space Hydrocarbons Natural Sinks Sulfur Dioxide Air Pollutant Removal Natural Soil/Vegetation Emissions Ammonia Nitrogen Oxides Carbon Monoxide PAN Chlorine Fluorine	

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VOLUME I: SINK FACTORS

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OPEN SPACE
AS AN
AIR RESOURCE
MANAGEMENT MEASURE
VOLUME I: SINK FACTORS

by

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Prepared for

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Office of Air and Waste Management
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October 1976

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STAFFING

Dr. Robert DeSanto was project manager and principal investigator of this study at COMSIS CORPORATION - Environmental Services. Dr. William H. Smith of the Yale University School of Forestry and Environmental Studies participated by providing guidance in the collection and interpretation of data and preparation of the tables from which emission and sink rates were extracted. Dr. Joseph A. Miller, Head Librarian at the Yale University School of Forestry and Environmental Studies, executed all library services and guided the numerous processing operations required for document delivery. Mr. William P. McMillen and Mr. Kenneth A. MacGregor of COMSIS CORPORATION assisted in all aspects of this study providing engineering and planning overviews.

Much of the data collection was undertaken and coordinated by Mrs. Audrey Hoffer, who was assisted by Ms. Dana Pumphrey and Mr. John Ruckes, and others.

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ABBREVIATIONS AND SYMBOLS

cm = centimeter
= 0.01 meter
= 10^{-2} meter

dm = decimeter
= 0.10 meter
= 10^{-1} meter

g = gram

ha = hectare
= 100^2 meters

hr = hour

in = inch

kg = kilogram
= 1000 grams
= 10^3 grams

l = liter

lbs = pounds

μg = microgram
= 0.000001 grams
= 10^{-6} grams

μl = microliter
= 0.000001 liters
= 10^{-6} liters

m = meter

mg = milligram
= 0.001 grams
= 10^{-3} grams

mi = mile

min = minute

nl = nanoliter
= 0.0000000001 liters
= 10^{-9} liters

ppb = parts per billion

pphm = parts per hundred million

ppm = parts per million

wk = week

NOTE: Conversion tables are contained in Appendix A of this volume.

I. INTRODUCTION, APPROACH AND SUMMARY OF RESULTS

A. INTRODUCTION AND ORGANIZATION OF THE REPORT

The work undertaken in this project has resulted in the preparation of three separate volumes. Taken together, they cite and attempt to interpret all of the pertinent and accessible literature from the United States of America, and elsewhere, relating to the potential use of open space as a practical means to mitigate air pollution.

Volume I, this volume, is entitled Sink Factors, and presents the data collected from the manual and computerized literature searches which were conducted when the project was begun. Most of the information presented in the other volumes was derived from the data contained in Volume I. Therefore, much cross referencing is made. Volume I contains tables of sink and emission factors which were developed based on the collected data. It also contains tables of pollution sensitive and pollution resistant plant species also derived from the surveyed literature. Chapter V of this Volume contains the Bibliography of pertinent literature which was prepared for this project. The abstracts of this literature is available through the National Technical Information Service as "Open Space" as an Air Resource Management Measure - Volume I Sink Factors (Abstracts). We feel that the literature search is very comprehensive and, therefore, may be helpful to future searchers which may deal with interests peripheral to our specific study area.

Volume II is entitled Design Criteria and presents the essence of this study in the form of a workbook. It reviews the primary biological and design features which are crucial to the effective utilization of open space to mitigate air pollution. It presents generalized schemes for the design and location of buffer strips and other forms of open space and also illustrates air pollution mitigation by open space by identifying the mathematical procedures necessary in order to permit the incorporation of the appropriate sink factors into four generally used carbon monoxide diffusion models.

Volume III is entitled Demonstration Plan and applies our findings in a hypothetical manner to a test city, St. Louis, Missouri. This demonstration plan includes a cost/effectiveness analysis of the open space/AQMA plan interdigitation based on the best available data which we were able to secure. It provides the reader with a realistic application and evaluation of using open space as a practical part of the AQMA plan strategy.

B. SUMMARY OF THE RESULTS

Of approximately eight thousand references examined, about two thousand were used because they were directly or indirectly relevent to determining the sink and emission factors of those pollutants under study. Information was collected on: 1) Ammonia, 2) Carbon monoxide, 3) Chlorine, 4) Fluorine, 5) Hydrocarbons, 6) Nitrogen oxides, 7) Ozone, 8) Peroxyactylnitrate (PAN), 8) Particulates, and 9) Sulfur dioxide. Sink and emission factors are reported from the literature and, where possible, the average factor is calculated based on a subjective evaluation of the data.

As a result of this study, it is clear that there is very little data available which quantitatively evaluates the function of water bodies as a sink and/or source of air pollutants. Most of the data we reviewed dealt with soil and vegetation relative to sinks and emissions and therefore, the imbalance of data causes this report to make only very general statements concerning the importance of water as a factor in open space mitigation of air pollution. Future research should focus on this area for both qualitative and quantitative analyses.

II. LITERATURE SEARCH STRATEGIES

A. CITATION SOURCES

The initial guidelines which were used in the project for searching the technical literature are contained in Appendix B of this volume. Using these guidelines, the technical staff read and abstracted papers retrieved by manual or computerized literature searches, as outlined below. In those instances where an adequate abstract already existed, its contents were checked against our guidelines and the abstract was edited as needed for inclusion in our file. Approximately two thousand pertinent abstracts were collected in this manner within the first three months of this study. The balance of the project effort was directed at the document delivery of the most important, or apparently important, papers for further data extraction and interpretation.

B. DOCUMENT DELIVERY

Simultaneously with the searching, those documents felt to be important for complete evaluations were sought. Often this meant going to libraries in search of the publication cited. In those cases, a photocopy of the paper was made and entered into our file which formed the basis for our final interpretations and data extraction.

The breakdown of secured documents includes approximately 80% as paper copies, 19% as microfiche copy and 1% as 35 mm microfilm. Of the untranslated foreign literature, we translated and evaluated pertinent sections of 136 papers, most of which were on microfiche. The national division of the selected papers was as follows:

63	German
49	Japanese
11	French
6	Russian
6	Eastern European
1	Scandinavian

In general, the foreign literature to which we had access was a poor source of information. This appears due to the unfortunate absence of good international communication which would disseminate the methodology of precise data recording from natural sinks and sources of air pollutants. Many of the papers examined neglected to describe experimental conditions and parameters such as the concentration of gases utilized in fumigation tests.

C. THE USED LITERATURE

The initial technical reviews of the selected literature resulted in constructing cross references to the various pertinent subjects in this study. They are listed here with reference to the indexing numbers which identify the specific references listed in Chapter V.

III. SINK AND EMISSION FACTORS

After reviewing all of the pertinent references accumulated and digesting and evaluating the particularly useful publications, it must be concluded that the data available for designing, creating or justifying "natural areas" to act as sinks for air contaminants is very limited. In recent conversations with several researchers working in this area, we find rather general agreement that only limited information is available at this time.

Basically, the limitations are imposed by the following considerations (not necessarily in their order of importance):

1) There is considerable literature, much of it European, that suggests natural areas are effective "sinks" but fail to provide quantification of their observations, or data to specifically support their conclusions.
2) Much of the data that has been provided regarding plant uptake of pollutants has been concerned with species not traditionally employed in conventional industrial or roadside landscape designs. Some of the best plant information has been generated using agricultural species, such as alfalfa.
3) Plant studies examining particulate or gaseous uptake are usually done under controlled environmental conditions. This means that most data has stemmed from greenhouse or controlled growth chamber/room situations. Very few field studies have been reported. The reason for this situation is straight forward. Much evidence has been provided to show that plant uptake and response to air contaminants is extremely variable and particularly subject to alterations by the following:
    a. temperature
    b. light intensity and quality
    c. humidity
    d. wind velocity
    e. age of tissue/organ
    f. substrate (soil) conditions
    g. health

Because of this multitude of variables, investigators have been forced to control as much variation as possible by utilizing environmentally controlled facilities.

It is clear that a plant's sink function in nature would be variable and complex as it would vary diurnally and seasonally. An accurate assessment of this variation, for any plant, is not available in the present literature.

4) Some evidence has been provided, some with woody plant species, that susceptibility to air contaminants is genetically controlled. This means that genetic considerations must be evaluated and generalizations cannot be made for entire species.

5) Investigations of pollutant uptake by plants and soils generally examines single contaminants. Much evidence recently provided suggests that the interactive nature of air contaminants is very important. Plant responses involving synergism, antagonism and simple add-on influence have been published.

   In the natural environment, plants may be exposed to numerous pollutants concurrently or within a relatively short period of time. This situation has not been adequately examined.

6) Most research has been done with small, frequently young individuals. Herbaceous species, including various agricultural species are particularly well suited for growth in cramped controlled environment facilities. Some work has been done with seedling woody plants. Research with sapling or mature woody species is almost non-existent. It is this latter kind of work, however, that would be most useful in landscape design efforts. Woody-plant physiological-research, for example, that dealing with photosynthesis or root metabolism, has indicated that there is considerable risk in extrapolating from the seedling to the mature situation.

7) Efforts to utilize literature data for extrapolation to field situations is frequently impossible because of the lack of simple, descriptive information concerning leaf biomass, leaf area indices, ground area coverage or similar information. For example, numerous papers record pollutant uptake on a per gram dry weight basis for some plant part. Unless you can

provide the appropriate dry weight estimation for your field situations, the data cannot be extrapolated. Estimations provided on a ground area basis are most useful for planning, but frequently impossible to derive for published studies.

8) In numerous reports, including some of the most useful, e.g. some of the carbon monoxide-soil uptake studies, it is clear that only a limited number of samples were taken. Replication is not adequate or marginal for extrapolation of "general" values.

9) Specific estimation of the importance to plants and soils as sources of air contaminants is deficient. Despite some excellent studies, for example, the release of hydrocarbons by trees, more must be done in this area so that accurate sink values can be presented.

10) The information available on the ability of aquatic ecosystems to act as sources and sinks of air contaminants is particularly poor. (See ADDENDUM.)

Despite these ten limitations, some general guidelines for landscape design regarding natural resource-air pollutant removal can be provided. It must be realized by all, however, that these are very general estimations based on extremely limited information. Particularly useful data has been provided for soil uptake of carbon monoxide. Much of this data was generated under field conditions. A generalized range of soil uptake for this important pollutant would seem possible. In additional situations, similar ranges of plant uptake can be estimated.

The following tables present factors which are mainly based on the best data which we could retrieve in 1976. A utility factor of 1, 2, or 3 is associated with each datum given. If the research was undertaken to interpret field data and the methods were felt to be appropriate, we assigned a utility factor of 1 to the work. We feel that these results are most useful and applicable to our study. Less applicable results are assigned a utility factor of 2 and less useful or applicable data are assigned a utility factor of 3. When factors were converted to the metric system (SI), the original literature factor is given in parentheses immediately below the converted number.

In order to utilize the data more generally, a subjective evaluation of the tables was made by the project team and a summary table was developed. In general, that summary table is based on selective averaging of the sink and emission factors for each pollutant. It is meant as a first rough approximation of the broadest interpretation of the reviewed literature. This summary table is designated Table III-11 and is located on page III-40.

TABLE III-1

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

AMMONIA

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
soybean	$410\ \mu g\ m^{-2}\ hr^{-1}$ $(4.1\ \mu g\ dm^{-2} hr^{-1})$		103	2
sunflower	$490\ \mu g\ m^{-2}\ hr^{-1}$ $(4.9\ \mu g\ dm^{-2} hr^{-1})$		103	2
corn	$560\ \mu g\ m^{-2} hr^{-1}$ $(5.6\ \mu g\ dm^{-2} hr^{-1})$		103	2
cotton	$350\ \mu g\ m^{-2} hr^{-1}$ $(3.5\ \mu g\ dm^{-2} hr^{-1})$		103	2
Comments:	Absorption rates determined in vitro at 3 nitrogen fertility levels.			
VEGETATION	Ammonia Nitrogen			
corn	$278.8\ \mu g\ m^{-2} hr^{-1}$ $(0.669\ \mu g\ cm^{-2} hr^{-1})$		104	2
Comments:	The rate of uptake was variable with ambient NH_3 levels and nitrogen fertilization. The maximum removal rate is presented here.			
SOIL				
Collington, New Jersey	$12.42\ \mu g\ 100\ g^{-1} hr^{-1}$ $(1.18\ mg\ \ 100g^{-1}\ 95^{-1}\ hr)$		986	2
Comments:	Uptake varied with soil type and length of exposure. Maximum value is given.			

AMMONIA

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Collington sandy loam	$335.6\ \mu g\ m^{-2}hr^{-1}$ $(32.6\ g\ acre^{-1}day^{-1})$		973	2
Dutchess loam	$570.4\ \mu g\ m^{-2}hr^{-1}$ $(55.4\ g\ acre^{-1}day^{-1})$		973	2
Lakewood sand	$234.7\ \mu g\ m^{-2}hr^{-1}$ $(22.8\ g\ acre^{-1}day^{-1})$		973	2
Matapeake silt loam	$940.0\ \mu g\ m^{-2}hr^{-1}$ $(91.3\ g\ acre^{-1}day^{-1})$		973	2
Dutchess shale loam	$369.6\ \mu g\ m^{-2}hr^{-1}$ $(35.9\ g\ acre^{-1}day^{-1})$		973	2
Nixon loam	$906.1\ \mu g\ m^{-2}hr^{-1}$ $(88.0\ g\ acre^{-1}day^{-1})$		973	2
Comments: Soil absorption of atmospheric NH_3 under field conditions .				
SOIL				
Nebraska prairie sod	$260.4\ \mu g\ m^{-2}hr^{-1}$ $(1\ kg\ ha^{-1}\ 160\ days^{-1})$		280	3
Comments: Experiment designed to measure the influence of moisture and tillage on NH_3 volatilization. Rate was experimental maximum.				
SOIL Under various vegetation types				
pine	$2030\ \mu g\ m^{-2}hr^{-1}$ $(3.41\ kg\ ha^{-1}wk^{-1})$		225	2
oak	$1565\ \mu g\ m^{-2}hr^{-1}$ $(2.63\ kg\ ha^{-1}wk^{-1})$		225	2
sod	$1095\ \mu g\ m^{-2}hr^{-1}$ $(1.84\ kg\ ha^{-1}wk^{-1})$		225	2

AMMONIA

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
four flooded tropical soils		Ammonia Nitrogen 7.991-82.19 $\mu g\ m^{-2}\ hr^{-1}$ (0.7-7.2 kg $ha^{-1}\ yr^{-1}$)	1946	2
Comments: Laboratory study				
SOIL				
State of New Jersey	Ammonia Nitrogen 228.3-684.9 $\mu g\ m^{-2} hr^{-1}$ (20 - 60 kg $ha^{-1}\ yr^{-1}$)		1279	2
Comments: Results from controlled experiments. Rate conditioned by temperature and NH_3 concentration.				
VEGETATION, SOIL (Unspecified)				
plant leaves and soil		Ammonia Nitrogen 433.8-1290 $\mu g\ m^{-2}\ hr^{-1}$ (38-113 kg $ha^{-1} yr^{-1}$)	225	3
WATER				
water surface	89.92-1667 $\mu g\ m^{-2} hr^{-1}$ (0.15-2.8 kg $ha^{-1} wk^{-1}$)		991	2
Comments: Range reflects field measurements taken at various distances from feedlots of various sizes. Lowest value represents a site with no feedlots or irrigated fields within 3 km and no large feedlots or cities within 15 km. Highest value is ~0.4 km west of 90,000 unit feedlot.				

TABLE III-2

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
algae	$292.2\ \mu g\ hr^{-1} gm^{-1}$ $(3.9\ cu\ mm\ gm^{-1}\ min^{-1})$		1433	3
Comments:	Assume fresh water algae dry wt basis. Experiment conducted at 26°C and 1 atm.			
~~**VEGETATION**~~				
bush bean	$3.22 \times 10^{3}\ \mu g\ hr^{-1}\ m^{-2}$ $(1.15\ \mu mole\ dm^{-2}\ hr^{-1})$		166	2
coleus	$0.70 \times 10^{3}\ \mu g\ hr^{-1}\ m^{-2}$ $(0.25\ \mu mole)$		166	2
cabbage	$22.4\ \mu g\ hr^{-1}\ m^{-2}$ $(0.008\ \mu mole)$		166	2
grapefruit	$56.0\ \mu g\ hr^{-1}\ m^{-2}$ $(0.02\ \mu mole)$		166	2
phoenix palm	$98.0\ \mu g\ hr^{-1}\ m^{-2}$ $(0.035\ \mu mole)$		166	2
climbing fig	$56.0\ \mu g\ hr^{-1}\ m^{-2}$ $(0.02\ \mu mole\ dm^{-2}\ hr^{-1})$		166	2
cucumber	$84.0\ \mu g\ hr^{-1}\ m^{-2}$ $(0.03\ \mu mole\ dm^{-2}\ hr^{-1})$		166	2
Comments:	Experiment based on detached exposed for periods of 5-15 min.			
VEGETATION				
sugar cane	$0.5\text{-}5 \times 10^{3}\ \mu g\ hr^{-1} m^{-2}$ $(0.5\text{-}5\ mg\ m^{-2} hr^{-1})$		209	3
Comments:	Calculated using leaf area indices of 3 to 30, and a value of $0.17 \times 10^{3}\ \mu g hr^{-1} m^{-2}$ for bean leaves. $(0.17\ mg\ m^{-2} hr^{-1})$			

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
(unspecified)	500-5,000 $\mu g\ hr^{-1}\ m^{-2}$ (12-120 $kg\ km^{-2}\ 24\ hr^{-1}$)		166	2
Comments:	Generalized fixation rate for vegetation of "intermediate" CO fixing capacity.			
VEGETATATION (unspecified)	500-5,000 $\mu g\ hr^{-1}\ m^{-2}$ (12-120 $kg\ km^{-2}\ 24\ hr^{-1}$)		746	3
Comments:	Estimate based on a bean plant extrapolation. Ambient concentration 200-369 ppm CO.			
SOIL				
forest soil: Charlton Fine Sandy Loam	22 x $10^3 \mu g\ hr^{-1}\ m^{-2}$ (0.22 $mg\ dm^{-2}\ hr^{-1}$)		988; 76	2
Comments:	This was maximum rate. Rate varied with moisture content and turbulence. Experiment conducted at ambient CO concentration of 28 ppm.			
SOIL forest/field soil (unspecified)	80 $\mu g\ hr^{-1}\ m^{-2}$ (8 x 10^{-4} $mg\ dm^{-2}\ hr^{-1}$)		988	1
Comments:	General estimate extrapolated from growth chamber data for ambient levels of CO averaging 40-65 ppm.			
SOIL potting soil	900 $\mu g\ hr^{-1}$ 2.8 kg^{-1}		10	3
Comments:	Soil composed of 95% Sandy Loam & 50% Canadian peat moss.			
SOIL potting soil (unspecified)	8.44 x $10^3 \mu g\ hr^{-1}\ m^{-2}$ (8.44 $mg\ m^{-2}\ hr^{-1}$)		82	2
Comments:	Figure represents average sink capacity of soils tested.			

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
total in temperate zone	191.1 metric tons sq mi^{-1} yr^{-1}		82	3
Comments: This represents a model estimate.				
SOIL				
along a 20-mile stretch of Bayshore Freeway (US 101)				
Embarcadero Road Interchange	64.5 x 10^3μg hr^{-1} m^{-2} (64.5 mg hr^{-1} m^{-2})		1275	2
San Antonio Road Interchange	47.9 x 10^3μg hr^{-1} m^{-2} (47.9 mg hr^{-1} m^{-2})		1275	2
Mathilda Avenue Interchange	52.5 x 10^3μg hr^{-1} m^{-2} (52.5 mg hr^{-1} m^{-2})		1275	2
W. Bayshore Rd. Interchange	43.0 x 10^3μg hr^{-1} m^{-2} (43.0 mg hr^{-1} m^{-2})		1275	2
Frontage Road Interchange	63.4 x 10^3μg hr^{-1} m^{-2} (63.4 mg hr^{-1} m^{-2})		1275	2
Dirt Road Interchange	32.7 x 10^3μg hr^{-1} m^{-2} (32.7 mg hr^{-1} m^{-2})		1275	2
San Tomas Expressway Interchange	36.9 x 10^3μg hr^{-1} m^{-2} (36.9 mg hr^{-1} m^{-2})		1275	2
Trimble Road Interchange	17.8 x 10^3μg hr^{-1} m^{-2} (17.8 mg hr^{-1} m^{-2})		1275	2
U.S. 85	22.6 x 10^3μg hr^{-1} m^{-2} (22.6 mg hr^{-1} m^{-2})		1275	2

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Mathilda Ave., Off Ramp	$16.2 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($16.2\ mg\ hr^{-1}\ m^{-2}$)		1275	2
W. Bayshore Road	$23.1 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($23.1\ mg\ hr^{-1}\ m^{-2}$)		1275	2
W. Bayshore Road	$15.0 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($15.0\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Comments:	Under lab conditions these rates varied in the temperature range 71°F-95°F. They also vary with moisture and organic chemical treatment of the soil.			
SOIL				
selected sites throughout North America				
Gila Bend, Ariz	$8.7 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($8.7\ mg\ hr^{-1}\ m^{-2}$)		1275	1
El Paso, Texas	$9.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($9.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Chihuahua, Chi.	$24.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($24.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Durango, Dur.	$9.2 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($9.2\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Etla, Oak.	$24.1 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($24.1\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Santa Domingo, Oax.	$74.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($74.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Palenque, Chi.	$28.8 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($28.8\ mg\ hr^{-1}\ m^{-2}$)		1275	1

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Palenque, Chi.	$14.0 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($14.0\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Palenque, Chi.	$28.3 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($28.3\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Champotoa, Camp.	$35.1 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($35.1\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Nerida, Yuc.	$43.1 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($43.1\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Minatitlan, V.C.	$58.0 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($58.0\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Posa Rica, V.C.	$13.5 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($13.5\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Tampico, V.C.	$83.5 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($83.5\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Tampico, V.C.	$109.0 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($109.0\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Monterrey, N.L.	$21.1 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($21.1\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Fort Stockton, Tex.	$14.6 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($14.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Winnemocca, Nev.	$7.5 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($7.5\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Monticello, Utah	$15.6 \times 10^{3} \mu g\ hr^{-1}\ m^{-2}$ ($15.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Douglas, Wyo.	$43.2 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(43.2\ mg\ hr^{-1}\ m^{-2})$		1275	1
Sabetha, Kansas	$30.4 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(30.4\ mg\ hr^{-1}\ m^{-2})$		1275	1
Columbia, Mo.	$38.2 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(38.2\ mg\ hr^{-1}\ m^{-2})$		1275	1
Athens, Ohio	$47.8 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(47.8\ mg\ hr^{-1}\ m^{-2})$		1275	1
Binghamton, N.Y.	$43.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(43.6\ mg\ hr^{-1}\ m^{-2})$		1275	1
Harris burg, Pa.	$19.8 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(19.8\ mg\ hr^{-1}\ m^{-2})$		1275	1
Charlottsville, VA.	$20.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(20.6\ mg\ hr^{-1}\ m^{-2})$		1275	1
Columbus, Ga.	$13.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(13.6\ mg\ hr^{-1}\ m^{-2})$		1275	1
Shrevesport, La.	$36.9 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(36.9\ mg\ hr^{-1}\ m^{-2})$		1275	1
Wichita Falls, Tex.	$41.3 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(41.3\ mg\ hr^{-1}\ m^{-2})$		1275	1
Alberquerque, N.M.	$15.4 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(15.4\ mg\ hr^{-1}\ m^{-2})$		1275	1
Donna Pass, Calif.	$17.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(17.6\ mg\ hr^{-1}\ m^{-2})$		1275	1

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Mt. Olive, Miss.	$15.2 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(15.2\ mg\ hr^{-1}\ m^{-2})$		1275	1
Stonelick, Pa.	$29.1 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(29.1\ mg\ hr^{-1}\ m^{-2})$		1275	1
Prairie View, Kans.	$24.3 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(24.3\ mg\ hr^{-1}\ m^{-2})$		1275	1
Egbert, Wyo.	$45.4 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(45.4\ mg\ hr^{-1}\ m^{-2})$		1275	1
Yellowstone Pk. Wyo.	$30.5 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(30.5\ mg\ hr^{-1}\ m^{-2})$		1275	1
Stockton, Calif.	$16.8 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(16.8\ mg\ hr^{-1}\ m^{-2})$		1275	1
Red Bluff, Calif.	$10.5 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(10.5\ mg\ hr^{-1}\ m^{-2})$		1275	1
Red Bluff, Calif.	$13.0 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(13.0\ mg\ hr^{-1}\ m^{-2})$		1275	1
Grants Pass, Oregon	$30.2 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(30.2\ mg\ hr^{-1}\ m^{-2})$		1275	1
Bellingham, Wash.	$51.8 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(51.8\ mg\ hr^{-1}\ m^{-2})$		1275	1
Bellingham, Wash.	$25.8 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(25.8\ mg\ hr^{-1}\ m^{-2})$		1275	1
Prince George, B.C.	$35.4 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(35.4\ mg\ hr^{-1}\ m^{-2})$		1275	1

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Prince George, B.C.	$26.0 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($26.0\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Watsons Lake, Yuk.	$28.0 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($28.0\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Haines Junction, Yuk.	$29.7 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($29.7\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Haines Junction, Yuk.	$22.0 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($22.0\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Haines Juncton, Yuk.	$20.3 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($20.3\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Croward, Alb.	$30.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($30.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1
McMurray, Alb.	$44.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($44.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1
St. Walburg, Sask.	$32.0 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($32.0\ mg\ hr^{-1}\ m^{-2}$)		1275	1
La Range, Sask.	$19.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($19.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1
La Range, Sask.	$20.6 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($20.6\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Hudson Bay, Man.	$17.3 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($17.3\ mg\ hr^{-1}\ m^{-2}$)		1275	1
Moosejaw, Sask.	$39.2 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($39.2\ mg\ hr^{-1}\ m^{-2}$)		1275	1

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Fort Benton, Mont.	$35.5 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(35.5\ mg\ hr^{-1}\ m^{-2})$		1275	1
Spokane, Wash.	$21.3 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(21.3\ mg\ hr^{-1}\ m^{-2})$		1275	1
Spokane, Wash.	$34.2 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(34.2\ mg\ hr^{-1}\ m^{-2})$		1275	1
Berns, Ore.	$12.8 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(12.8\ mg\ hr^{-1} m^{-2})$		1275	1
Prince Rupert, B.C.	$24.0 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(24.0\ mg\ hr^{-1}\ m^{-2})$		1275	1
Comments:	Figures derived from soils under field conditions. Data on soil pH, soil moisture and air temperature are also available.			
SOIL				
unspecified		$46\ \mu g\ hr^{-1}\ kg^{-1}$	10	3
Comments:	This rate was for an autoclaved soil sample, in light and at 40°C.			
SOIL				
unspecified				
El Paso	$5.52 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(5.52\ mg\ hr^{-1}\ m^{-2})$		1275	2
Chihuahua	$0.04 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(0.04\ mg\ hr^{-1}\ m^{-2})$		1275	2
Durango	$0.16 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(0.16\ mg\ hr^{-1}\ m^{-2})$		1275	2

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Daxaco (Etla)	$7.37 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($7.37\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Santa Domingo	$7.79 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($7.79\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Palenque (Tepa)	$4.29 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($4.29\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Palenque	$4.39 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($4.39\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Palenque	$15.36 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($15.36\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Champoton	$5.49 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($5.49\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Merida	$14.33 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($14.33\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Minatillan	$11.37 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($11.37\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Posa Rica	$9.02 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($9.02\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Tampico	$6.36 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($6.36\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Tampico	$1.13 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($1.13\ mg\ hr^{-1}\ m^{-2}$)		1275	2
Monterrey	$7.99 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($7.99\ mg\ hr^{-1}\ m^{-2}$)		1275	2

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Ft. Stockton	$1.60 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(1.60\ mg\ hr^{-1}\ m^{-2})$		1275	2
Ft. Stockton	$2.97 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(2.97\ mg\ hr^{-1}\ m^{-2})$		1275	2
Comments:	The removal rates are temperature dependent. These figures, at 30°C, are optimal. The experiment was conducted under lab conditions.			
SOIL				
unspecified - designated by location & vegetation type				
Eureka-Arcata, CA-coast redwoods	$16.99 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(16.99\ mg\ hr^{-1}\ m^{-2})$		10; 82	1
H. Cowell St. Pk., CA-oak	$15.92 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(15.92\ mg\ hr^{-1}\ m^{-2})$		10; 82	1
H. Cowell St. Pk., CA-coast redwoods	$14.39 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(14.39\ mg\ hr^{-1}\ m^{-2})$		10; 82	1
Lake Arrowhead, CA-Ponderosa Pine	$13.89 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(13.89\ mg\ hr^{-1}\ m^{-2})$		10; 82	1
Redding, CA-grass, legume pasture	$11.94 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(11.94\ mg\ hr^{-1}\ m^{-2})$		10; 82	1
Riverside, CA-grapefruit	$11.48 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(11.48\ mg\ hr^{-1}\ m^{-2})$		10; 82	1
Yosemite Valley, CA-grass meadow	$10.52 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(10.52\ mg\ hr^{-1}\ m^{-2})$		10; 82	1
Kauai, Hawaii - forest	$9.90 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ $(9.90\ mg\ hr^{-1}\ m^{-2})$		10; 82	1

CARBON MONOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
San Bernardino, CA-freeway, no vegetation	$6.89 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($6.89\ mg\ hr^{-1}\ m^{-2}$)		10;82	1
Mojave Desert, CA-chaparral	$6.46 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($6.46\ mg\ hr^{-1}\ m^{-2}$)		10;82	1
Woodland, CA-oak stubble	$6.23 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($6.23\ mg\ hr^{-1}\ m^{-2}$)		10;82	1
Riverside, CA-chaparral	$4.31 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($4.31\ mg\ hr^{-1}\ m^{-2}$)		10;82	1
Yosemite Wall, CA	$3.48 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($3.48\ mg\ hr^{-1}\ m^{-2}$)		10;82	1
Corcoran,CA.-cotton (follow)	$3.48 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($3.48\ mg\ hr^{-1}\ m^{-2}$)		10;82	1
Hanford,CA-almond	$2.82 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($2.82\ mg\ hr^{-1}\ m^{-2}$)		10;82	1
Boynton Beach,FLA weeds (follow)	$2.65 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($2.65\ mg\ hr^{-1}\ m^{-2}$)		10;82	1
Oahu, Hawaii	$2.16 \times 10^3 \mu g\ hr^{-1}\ m^{-2}$ ($2.16\ mg\ hr^{-1}\ m^{-2}$)		10;82	1

Comments: The pollutant removal mechanism was concluded to be biologic and aerobic. Soils with high organic matter and low pH were the most active.

TABLE III-3

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

CHLORINE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
alfalfa	2277.8 $\mu g\ m^{-2} hr^{-1} pphm^{-1}$ (12 $\mu\ell\ m^{-2}\ min^{-1}\ pphm^{-1}$)		523,88	2

TABLE III-4

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

FLUORINE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
alfalfa	101.7 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (22.5 $\mu\ell\ m^{-2}\ min^{-1}\ pphm^{-1}$)		88,523	2
alfalfa	1896 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (2.4 $ppm\ hr^{-1}\ pphm^{-1}$)		88	2
Comments:	First figure represents ground area basis. Bottom figure is based on the rate of accumulation.			
VEGETATION				
alfalfa	1.62×10^6 $\mu g\ gm^{-1}\ hr^{-1}$ (39 $mg\ gm^{-1}\ day^{-1}$)		165	3
Comments:	Experimental conditions involved 24 hr fumigation at 5.0 $\mu g\ m^{-3}$. It is assumed rate is dry weight of alfalfa.			
VEGETATION				
clover (timothy and red)	0.73×10^3 $\mu g\ gm^{-1} hr^{-1}$ (17.5 $mg\ gm^{-1} day^{-1}$)		1533	3
Comments:	It is assumed maximum value rate represents dry weight. Clover was continuously exposed to 2.3 $\mu g\ Fm^{-3}$ for 10 days.			

FLUORINE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
tomato	2.00×10^3 $\mu g\ m^{-3} hr^{-1}$ (60.85 ppm day^{-1})		136	2
tomato	2.64×10^3 $\mu g\ m^{-3} hr^{-1}$ (80.35 ppm day^{-1})		136	2
cotton	1.25×10^3 $\mu g\ m^{-3} hr^{-1}$ (38.07 ppm day^{-1})		136	2
cotton	0.88×10^3 $\mu g\ m^{-3} hr^{-1}$ (26.64 ppm day^{-1})		136	2
gladiolus	0.132×10^3 $\mu g\ m^{-3} hr^{-1}$ (4 ppm day^{-1})		136	2
gladiolus	0.080×10^3 $\mu g\ m^{-3} hr^{-1}$ (2.43 ppm day^{-1})		136	2

Comments: tomato removal at ambient conc. of 4 $\mu g\ m^{-3} day^{-1}$ for 14 days measured leaves

tomato removal at ambient conc. of 7 $\mu g\ m^{-3} day^{-1}$ for 14 days measured leaves

cotton removal at ambient conc. of 4 $\mu g\ m^{-3} day^{-1}$ for 14 days measured leaves

cotton removal at ambient conc. of 5 $\mu g\ m^{-3} day^{-1}$ for 14 days measured leaves

gladiolus removal at ambient conc. of 2 $\mu g\ m^{-3} day^{-1}$ for 9 days measured leaves

gladiolus removal at ambient conc. of 2 $\mu g\ m^{-3} day^{-1}$ for 7 days measured leaves

TABLE III-5

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

HYDROCARBONS

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
		α pinene		
white pine		$1.20\ \mu g\ gm^{-1}hr^{-1}$ (2.0 ppb $gm^{-1}min^{-1}$)	95	2
ponderosa pine		$0.72\ \mu g\ gm^{-1}hr^{-1}$ (1.2 ppb $gm^{-1}min^{-1}$)	95	2
loblolly pine		$2.1\ \mu g\ gm^{-1}hr^{-1}$ (3.5 ppb $gm^{-1}min^{-1}$)	95	2
white fir		$0.90\ \mu g\ gm^{-1}hr^{-1}$ (1.5 ppb $gm^{-1}min^{-1}$)	95	2
		isoprene		
oak		$2232\ \mu g\ m^{-2}hr^{-1}$ (2.4 ppb $in^{-2}min^{-1}$)	95	2
sweet-gum		$1302\ \mu g\ m^{-2}hr^{-1}$ (1.4 ppb $in^{-2}min^{-1}$)	95	2
eucalyptus		$771.9\ \mu g\ m^{-2}hr^{-1}$ ($.83$ ppb $in^{-2}min^{-1}$)	95	2
cottonwood		$1116\ \mu g\ m^{-2}hr^{-1}$ (1.2 ppb $in^{-2}min^{-1}$)	95	2

Comments: Emission is dependent on rate of transpiration, structural integrity of the oil cells, resin glands, temperature of the foliage and intensity of light. Leaf dry wt and leaf area basis. Pollutants collected under growth chamber conditions: α pinene at 30-32°C, isoprene at 28°C. Emission rates are on a leaf dry wt and leaf area basis.

HYDROCARBONS

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
global		$1035.6 \times 10^{12}\ \mu g\ hr^{-1}$ (100 million tons year^{-1})	272	3
Comments: Emission of olefin-like substances, model estimate.				
VEGETATION				
coniferous forest		$5{,}178 \times 10^{12}\ \mu g\ hr^{-1}$ (50×10^{6} tons yr^{-1})	293	3
hardwood forest) cultivated land) total steppes)		$5{,}178 \times 10^{12}\mu g\ hr^{-1}$ (50×10^{6} tons yr^{-1})	293	3
microbial decomposition of organic matter		$7{,}249 \times 10^{12}\mu g\ hr^{-1}$ (70×10^{6} tons yr^{-1})	293	3
Comments: Model estimates for terpene-like compounds.				
VEGETATION		**Ethylene**		
monterey pine		$3{,}129 \times 10^{-3}\ \mu g\ gm^{-1}hr^{-1}$ (2.5×10^{-9} ℓ g^{-1} wood hr^{-1})	80	2
Comments: Rate is for stem wood of dominant pines. Calculated on a dry wood basis.				
VEGETATION		**Ethylene**		
unspecified		$0{,}6257 \times 10^{-3}\ \mu g\ gm^{-1}hr^{-1}$ (.5 nℓ gm^{-1} hr^{-1})	79	3
Comments: Gross estimate based on tissue fresh weight.				
VEGETATION				
forests-unspecified	1 ton C^{-1} yr^{-1}		1127	3
Comments: Model estimate .				

HYDROCARBONS

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
unspecified		$20,712 \times 10^{12}$ µg hr^{-1} (200×10^{6} ton yr^{-1})	1594	3
Comments: Terpene emission based on a model.				
SOIL				
microorganisms-unspecified	724.9×10^{12} µg hr^{-1} (7×10^{6} tons yr^{-1})		370	3
Comments: Model estimate of ethylene uptake for entire U.S.				

TABLE III-6

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

NITROGEN OXIDES

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
alfalfa	169.20×10^5 µg $m^{-2}hr^{-1}$ (150 µℓ NO_2 m^{-2} min^{-1})		55	2
oats	174.84×10^5 µg $m^{-2}hr^{-1}$ (155 µℓ NO_2 m^{-2} min^{-1})		55	2
Comments:	These uptake rates were calculated with 24 pphm NO_2 in the atmosphere. Uptake rates declined or remained stable as a function of time. They also varied according to the ambient concentration of NO_2 and intensity of light.			
VEGETATION				
alfalfa	4.43×10^4 µg $m^{-2}hr^{-1}$ (.6 µℓ NO m^{-2} min^{-1})		88	2
VEGETATION				
alfalfa	7.31×10^6 µg $m^{-2}hr^{-1}pphm^{-1}$ (12 µℓ NO_2 $m^{-2}min^{-1}pphm^{-1}$)		523	2
VEGETATION				
alfalfa	3.63×10^3 µg $m^{-2}hr^{-1}$ (1/4 ton sq $mile^{-1}day^{-1}$)		1413	3
Comments:	Model estimates for air similar to Los Angeles at 6 pphm.			
VEGETATION				
alfalfa	4.08×10^3 µg $m^{-2}hr^{-1}$ (2.04×10^5 lbs sq $mi^{-1}yr^{-1}$)		86	3
Comments:	Estimated from a model.			

NITROGEN OXIDES

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
unspecified	742 $\mu g\ m^{-2}hr^{-1}$ (72 gm NO_2 $acre^{-1}$ day^{-1})		200	2
Comments:	This rate was determined at 2 pphm NO_2 concentration. It varied with different ambient NO_2 concentrations.			
VEGETATION				
unspecified	4.09×10^3 $\mu g\ m^{-2}hr^{-1}$ (560 lbs NO_2 mi^{-2} day^{-1})		120	2
Comments:	Rates determined at 6 pphm ambient NO_2 levels.			
VEGETATION				
unspecified	742 $\mu g\ m^{-2}hr^{-1}$ (72 gm $acre^{-1}$ day^{-1})		55;64	3
Comments:	The removal rate is a model estimate calculated at an average 24 hr concentration of 2 pphm.			
SOIL				
sod-podzolic		2.02×10^2 $\mu g\ m^{-2}hr^{-1}$ (2.02 NO_2 g $ha^{-1}hr^{-1}$)	974	2
Comments:	This was the maximum rate recorded. Emission rates varied with experimental manipulation and fertilizer treatments.			
SOIL				
total in U.S.	103.6×10^6 $\mu g\ hr^{-1}$ (6×10^{10} tons $year^{-1}$)		370	3
Comments:	Estimated from a model.			
SOIL				
unspecified		2.00×10^2 $\mu g\ m^{-2}hr^{-1}$ (2 g NO_2 $ha^{-1}hr^{-1}$)	56	2
Comments:	The emission rate is dependent on soil nitrate and is zero during darkness. Nitrogen dioxide evolves from the soil as an eventual decomposition product of nitrate.			

TABLE III-7

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

OZONE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
alfalfa	2.80×10^3 μg $hr^{-1}m^{-2}pphm^{-1}$ (10 μl $m^{-2}min^{-1}pphm^{-1}$)		88	2
Comments:	Ozone removal may deviate from linearity above 10 pphm. The uptake varied with velocity and O_3 concentration.			
VEGETATION				
alfalfa	65.8×10^4 μg $hr^{-1}m^{-2}$ (900 lbs sq $mile^{-1}$ day^{-1})		64	2
snow white (South African shrub, scarcely cultivated)	55.6×10^4 μg $hr^{-1}m^{-2}$ (760 lbs sq $mile^{-1}$ day^{-1})		64	2
VEGETATION				
forest	1×10^4 μg $hr^{-1}m^{-2}$ of land (1 μg cm^{-2} (of land) hr^{-1}) 5×10^4 μg 8 $hr^{-1}m^{-2}$ of land (5 μg cm^{-2} (of land) 8 hr^{-1})		1127	2
Comments:	Estimates of depletion of an ozone containing air over a hypothetical forest.			
VEGETATION				
tree - unspecified	8.54×10^4 μg hr^{-1} $tree^{-1}$ (0.0045 lbs $tree^{-1}$ 24 hr^{-1})		398	3
Comments:	The following assumptions were made - leaf area of 4×10^6 cm^2 (4300 sq. ft.), average O_3 concentration of 0.17 ppm per 8 hr day, O_3 diffusion resistance of 0.33 min cm^{-1}.			

OZONE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
forest trees				
white oak	$63.5 \times 10^3\ \mu g\ hr^{-1}m^{-2}$ $(0.635\ mg\ dm^{-2}hr^{-1})$		379	2
	$131.8 \times 10^3\ \mu g\ hr^{-1}g^{-1}$ $(1.318\ mg\ g^{-1}hr^{-1})$		379	2
white birch	$53.6 \times 10^3\ \mu g\ hr^{-1}m^{-2}$ $(0.536\ mg\ dm^{-2}hr^{-1})$		379	2
	$234.7 \times 10^3\ \mu g\ hr^{-1}g^{-1}$ $(2.347\ mg\ g^{-1}hr^{-1})$		379	2
coliseum maple	$50.2 \times 10^3\ \mu g\ hr^{-1}m^{-2}$ $(0.502\ mg\ dm^{-2}hr^{-1})$		379	2
	$99.1 \times 10^3\ \mu g\ hr^{-1}g^{-1}$ $(0.991\ mg\ g^{-1}hr^{-1})$		379	2
sugar maple	$37.1 \times 10^3\ \mu g\ hr^{-1}m^{-2}$ $(0.371\ mg\ dm^{-2}hr^{-1})$		379	2
	$86.3 \times 10^3\ \mu g\ hr^{-1}g^{-1}$ $(0.863\ mg\ g^{-1}hr^{-1})$		379	2
Ohio buckeye	$36.2 \times 10^3\ \mu g\ hr^{-1}m^{-2}$ $(0.362\ mg\ dm^{-2}hr^{-1})$		379	2
	$92.7 \times 10^3\ \mu g\ hr^{-1}g^{-1}$ $(0.927\ mg\ g^{-1}hr^{-1})$		379	2
redvein maple	$28.5 \times 10^3\ \mu g\ hr^{-1}m^{-2}$ $(0.285\ mg\ dm^{-2}hr^{-1})$		379	2
	$91.1 \times 10^3\ \mu g\ hr^{-1}g^{-1}$ $(0.911\ mg\ g^{-1}hr^{-1})$		379	2

OZONE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
forest trees (Con't)				
sweetgum	27.8×10^{3} μg hr^{-1}m^{-2} (0.278 mg dm^{-2}hr^{-1})		379	2
	85.4×10^{3} μg hr^{-1}g^{-1} (0.854 mg g^{-1}hr^{-1})		379	2
red maple	27.2×10^{3} μg hr^{-1}m^{-2} (0.272 mg dm^{-2}hr^{-1})		379	2
	55.5×10^{3} μg hr^{-1}g^{-1} (0.555 mg g^{-1}hr^{-1})		379	2
white ash	23.9×10^{3} μg hr^{-1}m^{-2} (0.239 mg dm^{-2}hr^{-1})		379	2
	56.2×10^{3} μg hr^{-1}g^{-1} (0.562 mg g^{-1}hr^{-1})		379	2

Comments: All work was done with seedlings at ambient O_3 concentrations of 9.20 ppm. Area basis results are expressed as foliar surface (plane at top of canopy), as g^{-1}, assumed to be a leaf dry weight basis.

SOIL				
uncropped-Connecticut	$31.7\text{-}49.0 \times 10^{8}$ μg hr^{-1}m^{-2} ($11\text{-}17 \times 10^{-11}$molecules cm^{-2}sec^{-1})		740	2
corn (on same soil, additional removal over soil removal)	$0\text{-}66.2 \times 10^{6}$ μg hr^{-1}m^{-2} ($0\text{-}23 \times 10^{-11}$molecules cm^{-2}sec^{-1})		740	2

Comments: Results of field data.

OZONE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
Connecticut Cheshire fine sand loam	$86.4\text{-}345.6 \times 10^{7}$ µg $hr^{-1}m^{-2}$ ($3\text{-}12 \times 10^{11}$ molecules $cm^{-2}sec^{-1}$ 1×10^{11} molecules cm^{-3} = 4 ppb = 8 µg m^{-3})		81	1

Comments: Data obtained from field measurements. Uptake dependent on ventilation and genration of O_3 near the soil.

Another rate referenced in this paper was given for an ozone concentration of 10×10^{11} molecules cm^{-3} .

ecosystem element	removal rate	emission rate	ref	utility factor
sand or dry grass (in New Mexico)	72.0×10^{7} µg $hr^{-1}m^{-2}$ (2.5×10^{11} molecules $cm^{-2}sec^{-1}$)			

TABLE III-8

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

PAN (Peroxyacetylnitrate)

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
alfalfa	1199 $\mu g\ m^{-2} hr^{-1} pphm^{-1}$ ($3.7\ \mu\ell\ m^{-2} min^{-1} pphm^{-1}$)		523,88	2

Comments: Determined under growth chamber conditions with varying ambient concentration of PAN. Uptake rate was constant between 5 and 10 pphm.

TABLE III-9

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

PARTICULATES

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
bean	$1.53\ \mu g\ m^{-2}hr^{-1}$ $(.55\ pg\ cm^{-2}sec^{-1})$		1977	2
Comments:	Rate reflects deposition rate of unspecified aerosols on bean leaves. Rate varied with duration of exposure.			
VEGETATION				
bean	$0.56\text{-}1.70\ \mu g\ m^{-2}hr^{-1}$ $(.200\text{-}.613\ pg\ cm^{-2}sec^{-1})$		1091	3
Comments:	These unspecified aerosol particles varied in size from 0.443 - 1.999 μm. The experiment was conducted in a windtunnel.			
VEGETATION				
mango	$34.7\text{-}41.7 \times 10^{4}\ \mu g\ m^{-2}hr^{-1}$ $(25\text{-}30\ mg\ cm^{-2}month^{-1})$		3	2
lemon	$12.5\text{-}16.7 \times 10^{4}\ \mu g\ m^{-2}hr^{-1}$ $(9\text{-}12\ mg\ cm^{-2}month^{-1})$		3	2
Comments:	Coal dust settling in vivo found to be variable with maxima in April.			
VEGETATION				
sunflower	$1500\ \mu g\ m^{-2}hr^{-1}$ $(0.0025\ \mu g\ cm^{-2}min^{-1})$		143	3
tulip tree	$300\ \mu g\ m^{-2}hr^{-1}$ $(0.005\ \mu g\ cm^{-2}min^{-1})$		143	3
Comments:	Uranine dye particles, 6.72 μm. Controlled conditions assumed.			

PARTICULATES

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
sunflower	1800 μg m^{-2}hr^{-1} (0.003 μg cm^{-2}min^{-1})		143	3
Comments:	PbCl particles with 3.36 μm diameter. Controlled conditions assumed.			
VEGETATION				
hardwood canopy	1.79 x 10^{3} μg m^{-2}hr^{-1} (30 ton sq mi^{-1} 8 mon^{-1})		147	2
conifer canopy	6.28 x 10^{3} μg m^{-2}hr^{-1} (105 ton sq mi^{-1} 8 mon^{-1})		147	2
Comments:	Rates of unspecified dustfall, March through October field study in Ohio. Areas are for ground surface.			
VEGETATION				
chestnut (unspecified)	274.1 μg m^{-2}hr^{-1} (1 g m^{-2} 5 mo^{-1})		425	3
Comments:	Area equals leaf surface.			
VEGETATION/SOIL				
	0.1142 μg m^{-2}hr^{-1} (1 mg Pb m^{-2} yr^{-1})		1266	3
Comments:	This is the current estimated Pb deposition due to car exhaust in the western hemisphere.			
CADMIUM				
VEGETATION				
urban sugar maple	13.7 μg tree^{-1} hr^{-1} (60 mg tree^{-1} six months^{-1})		86	2
Comments:	This rate reflects a removal estimate for leaves and twigs of a 30 cm diameter urban sugar maple for a single growing season.			
LEAD				
VEGETATION				
urban sugar maple	1324 μg tree^{-1} hr^{-1} (5800 mg Pb tree^{-1} six months^{-1})		86	2
Comments:	This rate reflects a removal estimate for leaves and twigs of a 30 cm diameter urban sugar maple for a single growing season.			

TABLE III-10

SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

SULFUR DIOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
alfalfa	21.38×10^5 µg m^{-2} hr^{-1} (13.6 µℓ $m^{-2}min^{-1}pphm^{-1}$)		88;523	1
Comments:	Rate varied relative to ambient SO_2 concentration. Calculated under field conditions.			
VEGETATION				
alfalfa	8202.9×10^3 µg m^{-2} hr^{-1} (562 tons mi^{-1} day^{-1})		64	3
Comments:	Rate based on model.			
VEGETATION				
alfalfa	3.649×10^3 µg m^{-2} hr^{-1} (1/4 ton sq $mile^{-1}$ day^{-1})		1413	3
Comments:	Rate based on model.			
VEGETATION				
alfalfa	144.96×10^3 µg m^{-2} hr^{-1} (7.25×10^6 lbs sq $mile^{-1}$ yr^{-1})		86	3
Comments:	Rate based on model.			
VEGETATION				
mustard	669.6 µg m^{-2} hr^{-1} (18.6×10^{-12} gm cm^{-2} sec^{-1})		169	2
Comments:	Absorption of atmospheric S performed under laboratory conditions. Vertical deposition velocity constant was 0.74 cm_2 sec^{-1} .			

SULFUR DIOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
forest trees and alfalfa				
red maple	88 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (8.8×10^{-4} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$)		1970	2
white birch	86 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (8.6×10^{-4} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$)		1970	2
sweet gum	74 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (7.4×10^{-4} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$)		1970	2
white ash	46 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (4.6×10^{-4} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$)		1970	2
alfalfa	2900 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (2.9×10^{-2} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$*)		1970	2
alfalfa	620 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (6.2×10^{-3} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$)		1970	2
loblolly pine	700 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (7.0×10^{-3} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$*+)		1970	2
loblolly pine	120 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (1.2×10^{-3} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$+)		1970	2
loblolly pine	980 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (9.8×10^{-3} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphm^{-1}$*‡)		1970	2
loblolly pine	98 $\mu g\ m^{-2}\ hr^{-1}\ pphm^{-1}$ (9.8×10^{-4} SO_2 $kg\ ha^{-1}\ hr^{-1}\ pphmv^{-1}$‡)		1970	2

Note: * Based on ground surface area, other values based on leaf surface areas.

+ January simulation

‡ July simulation

Comments: Comparison of model and laboratory experiments, not field data. Seedling plants were employed.

SULFUR DIOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
hawthorn hedge (4 m high, 3 m side)	$157.2\ \mu g\ hr^{-1}$ $(6\ pphm\ hr^{-1})$		130	3
Comments: Field study near a British power plant.				
VEGETATION				
rhododendron	$81 \times 10^2\ \mu g\ m^{-2}hr^{-1}$ $(.081\ SO_2\ mg\ dm^{-2}hr^{-1})$		1972	2
	$127\ \mu g\ g^{-1}hr^{-1}$ $(.127\ SO_2\ mg\ g^{-1}hr^{-1})$		1972	2
firethorn	$128 \times 10^2\ \mu g\ m^{-2}hr^{-1}$ $(.128\ SO_2\ mg\ dm^{-2}hr^{-1})$		1972	2
	$272\ \mu g\ g^{-1}hr^{-1}$ $(.272\ SO_2\ mg\ g^{-1}hr^{-1})$		1972	2
Comments: Uptake of ambient SO_2 in a closed fumigation system by seedlings (?) of rhododendron and firethorn. Second figure assumed based on leaf dry weight.				
VEGETATION				
birch	$268\ \mu g\ g^{-1}hr^{-1}$ $(.268\ mg\ SO_2\ g^{-1}h^{-1})$		127	2
ash	$115\ \mu g\ g^{-1}hr^{-1}$ $(.115\ mg\ SO_2\ g^{-1}h^{-1})$		127	2
firethorn	$222\ \mu g\ g^{-1}hr^{-1}$ $(.222\ mg\ SO_2\ g^{-1}h^{-1})$		127	2
azalea	$71\ \mu g\ g^{-1}hr^{-1}$ $(.071\ mg\ SO_2\ g^{-1}h^{-1})$		127	2
Comments: Foliar sorption of these species for 1 hour in an open system varied with the SO_2 concentration in the atmosphere.				

SULFUR DIOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
VEGETATION				
forest-unspecified	3.33×10^{3} μg m^{-2} hr^{-1} (80 mg m^{-2} day^{-1})		64	3
Comments:	Rate based on model. Dry leaves assumed equivalent to 1 kg m^{3} .			
VEGETATION				
unspecified	14.65×10^{3} μg m^{-2} hr^{-1} (830 lbs SO_2 $mile^{-1}$ hr^{-1})		121	3
Comments:	A gross calculation predicted at 50 pphm ambient SO_2 concentration.			
VEGETATION				
unspecified	145.37×10^{3} μg m^{-2} hr^{-1} (830 lbs sq $mile^{-1}$ hr^{-1})		523	3
Comments:	Based on an ambient concentration of 50 pphm.			
SOIL				
oolitic limestone	168×10^{3} μg m^{-2} hr^{-1} (0.28 μg SO_2 cm^{-2} min^{-1})		955	2
Comments:	Maximum value obtained at 81% relative humidity at an ambient SO_2 concentration of 370 μg m^{-3} . Other values varied with relative humidity, concentration of SO_2 in the atmosphere, and time of exposure.			
SOIL				
total in U.S.	41.42×10^{15} μg hr^{-1} (4×10^{8} ton yr^{-1})		370	3
Comments:	Rate based on model.			

SULFUR DIOXIDE

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
European	Deposition Velocity			
Rendsina	.60 SO_2 cm 3200 cm^{-2} sec^{-1}		1254	2
alluvial glay	.56 SO_2 cm 3200 cm^{-2} sec^{-1}		1254	2
parabrown	.54 SO_2 cm 3200 cm^{-2} sec^{-1}		1254	2
podsol	.47 SO_2 cm 3200 cm^{-2} sec^{-1}		1254	2
terra fusca	.52 SO_2 cm 3200 cm^{-2} sec^{-1}		1254	2
pseudo glay	.42 SO_2 cm 3200 cm^{-2} sec^{-1}		1254	2
fen	.38 SO_2 cm 3200 cm^{-2} sec^{-1}		1254	2

Comments: Rates obtained under growth chamber conditions. Rates varied with relative humidity and pH. 3200 cm^{-2} is the tray area. Higher rates indicate relative effectiveness of SO_2 removal by that test soil.

ecosystem element	removal rate	emission rate	ref	utility factor
SOIL				
acid soil-unspecified	11520 x 10^3 μg m^{-2} hr^{-1} (2 x 10^{-7} μℓ H_2S cm^{-2} min^{-1})		56	2

ecosystem element	removal rate	emission rate	ref	utility factor
WATER				
lake surface	325 μg SO_{-4} m^{-2} hr^{-1} (234 kg SO_{-4} km^{-2} mo^{-1})		1184	2

Comments: Average dry deposition (input in precipitation excluded) during August and September in a German lake.

SUMMARY OF SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

TABLE III - 11

SUMMARY OF SINK AND EMISSION FACTORS FOR NATURAL ELEMENTS

Pollutant	Ecosystem Element	Removal Rate	Emission Rate
AMMONIA	Vegetation	400 $\mu g\ m^{-2}\ hr^{-1}$	
	Soil	550 $\mu g\ m^{-2}\ hr^{-1}$	
	Soil (dry)		1500 $\mu g\ m^{-2} hr^{-1}$
	Soil (flooded)		50 $\mu g\ m^{-2} hr^{-1}$
	Water	900 $\mu g\ m^{-2}\ hr^{-1}$	
CARBON MONOXIDE	Vegetation	2500 $\mu g\ m^{-2}\ hr^{-1}$	
	Soil	20,000 $\mu g\ m^{-2}\ hr^{-1}$	
CHLORINE	Vegetation	2,000 $\mu g\ m^{-2}\ hr^{-1}$	
FLUORINE	Vegetation	100 $\mu g\ m^{-2}\ hr^{-1}$	
HYDROCARBONS	Vegetation		7.01 $\mu g\ m^{-2} hr^{-1}$
	Soil	4.91 $\mu g\ m^{-2}\ hr^{-1}$	
NITROGEN OXIDES	Vegetation	2,000 $\mu g\ m^{-2}\ hr^{-1}$	
	Soil	200 $\mu g\ m^{-2}\ hr^{-1}$	
OZONE	Vegetation	80,000 $\mu g\ m^{-2}\ hr^{-1}$	
	Soil	1,000,000,000 $\mu g\ m^{-2}\ hr^{-1}$	
PAN	Vegetation	1199 $\mu g\ m^{-2}\ hr^{-1}$	
PARTICULATES	Vegetation	4,000 $\mu g\ m^{-2}\ hr^{-1}$	
SULFUR DIOXIDE	Vegetation	500 $\mu g\ m^{-2}\ hr^{-1}$	
	Soil	11,500 x 10^3 $\mu g\ m^{-2}\ hr^{-1}$	
	Water	300 $\mu g\ SO_4\ m^{-2}\ hr^{-1}$	

IV. PLANT SPECIES SENSITIVITY LISTS

Based on the literature surveyed, a table has been constructed which lists plant species which are relatively tolerant or which are relatively sensitive to air pollutants. In some instances, scientific or common names as they appeared in the original literature were antiquated. Where that occurred, the names were appropriately changed to correspond with currently accepted botanical standards of nomenclature. The common name list follows.

TABLE IV- 1

PLANT SPECIES SENSITIVITY LISTS

Fluorine

TOLERANT - Trees/Deciduous

	Reference
Apple *Malus sp.*	733
American elm *Ulmus americana*	1164, 536
American linden (Basswood) *Tilia americana*	1164, 536
American mountain ash *Sorbus domestica*	536
American sycamore *Platanus occidentalis*	733
Basswood (American linden) *Tilia americana*	1164, 536
Cornelian cherry *Cornus mas*	1164, 536
Cutleaf birch *Betula pendula var. gracilis*	536
European black alder *Alnus glutinosa*	536, 1164
European elder *Sambucus nigra*	536
European larch *Larix decidua*	1687
European mountain ash *Sorbus aucuparia*	1164, 536
European red elder *Sambucus racemosa*	536
Flowering dogwood *Cornus florida*	733
Flowering plum *Prunus cerasifera*	1164, 536
Hackberry *Celtis sp.*	733
Litte leaf linden *Tilia cordata*	536
Modesto ash *Fraxinus velutina*	1164, 536
Norway maple *Acer platanoides*	733
Oleaster (Russian Olive) *Eleagnus angustifolia*	536
Oriental cherry *Prunus serrulata*	536
Pear *Pyrus communis*	1164
Russian olive (Oleaster) *Eleagnus angustifolia*	536
Sugar maple *Acer saccharum*	1164
Tree of heaven *Ailanthus altissima*	536
Willow *Salix sp.*	536, 1164
White birch *Betula alba*	733
White mulberry *Morus alba*	733

TOLERANT - Trees/ Coniferous

American holly *Ilex opaca*	733
Austrian pine *Pinus nigra*	1164
Canadian hemlock (Hemlock) *Tsuga canadensis*	733
Eastern red cedar *Juniperus virginiana*	525
Hemlock (Canadian hemlock) *Tsuga canadensis*	733
Juniper *Juniperus sp.*	1164, 536
Magnolia *Magnolia sp.*	733
Western hemlock *Tsuga heterophylla*	1687
White spruce *Picea glauca*	1164, 536

TOLERANT - Shrubs

Bridal wreath spirea *Spirea prunifolia*	1164
Currant *Ribes sp.*	1164
Firethorn *Pyracantha sp.*	1164

TOLERANT - Herbaceous

Alfalfa *Medicago Sativa*	16

Fluorine (Con't)

TOLERANT - Herbaceous

	Reference
Apricot - vine *Passiflora sp.*	886C
Celery *Spermolepsis sp.*	16
Cotton *Gossypium sp.*	136, 16, 269
Cucumber *Sicyos sp.*	16
Eggplant *Solanum melongena*	16
Fescue *Festuca elator*	890N
Geranium *Geranium sp.*	16
Gladiolus	886C
Grapevine *Vitis sp.*	886C
Kentucky bluegrass *Poa pratensis*	890N
Red Fescue *Festuca sp.*	890N
Sweet clover *Melilotus sp.*	16
Tobacco *Nicotiana sp.*	16

INTERMEDIATE - Trees/Deciduous

Apple *Malus sp.*	16
Black locust *Robinia pseudoacacia*	1164, 536
Black walnut *Juglans nigra*	536
Cutleaf birch *Betula pendula var. gracilis*	16
English oak *Quercus robor*	536
English walnut (Persian walnut) *Juglans regia*	1164, 536
Eugene poplar *Populus canadensis var. jugenci*	1164, 536
European ash *Fraxinus excelsior*	1164, 536
European beech *Fagus sylvatica*	536
European filbert *Corylus avellana*	536
European hornbeam *Carpinus betulus*	536
European white birch *Betula pendula*	536
Green ash *Fraxinus pennsylvanica lanceolata*	536, 1164
Hedge maple *Acer campestre*	536, 1164
Japanese larch *Larix leptolepsis*	1074
Little leaf linden *Tilia cordata*	1164, 536
Lombardy poplar *Populus nigra var. italica*	1164, 536
Oriental cherry *Prunus serrulata*	1164
Oriental plane tree *Platanus orientalis*	536
Persian walnut (English walnut) *Juglans regia*	1164, 536
Quaking aspen *Populus tremuloides*	1164, 536
Red mulberry *Morus rubra*	536
Serviceberry *Amelanchier canadensis*	1164
Silver maple *Acer saccharinum*	1164, 536
Smooth sumac *Rhus glabra*	536
Spanish chestnut *Castenea sativa*	536

INTERMEDIATE - Trees/ Coniferous

Aborvitae *Thuja sp.*	536, 1164
Austrian pine *Pinus nigra*	525
Douglas fir *Pseudotsuga menziesii*	1074
English holly *Ilex aquifolium*	1164, 536
Lodgepole pine *Pinus contorta*	1074

Fluorine (Con't)

INTERMEDIATE - Trees/ Coniferous

	Reference
Noble fir *Abies procera*	1074
Ponderosa pine *Pinus ponderosa*	1074
Spruce *Picea sp.*	1074
Western hemlock *Tsuga heterophylla*	1074
Western red cedar *Juniperus scopulorum*	1074
Western white pine *Pinus monticola*	1074
White fir *Abies concolor*	1074

INTERMEDIATE - Shrubs

Common lilac *Syringa vulgaris*	1164
Japanese yew *Taxus cuspidata*	1164, 536
Rhododendron *Rhododendron sp.*	1164
Rose *Rosa sp.*	1074, 1164, 16

INTERMEDIATE - Herbaceous

Buckwheat *Fagopyrum*	16
Iris *Iris sp.*	16

SENSITIVE - Trees/Deciduous

Apricot (Flowering apricot) *Prunus armeniaca*	536, 16, 460
Box elder *Acer negundo*	536, 1164
Bradshaw plum *Prunus domestica 'Bradshaw'*	536, 1164
Empress tree *Paulownia tomentosa*	536
Flowering apricot (Apricot) *Prunus armeniaca*	536, 16, 460
Hop hornbeam *Carpinus betulus*	765
Italian prunes *Prunus sp.*	269
Japanese apricot *Prunus mume*	363
Maple *Acer sp.*	765
Moorhead apricot	363
Paulownia (Empress tree) *Paulownia tomentosa*	536
Plum *Prunus sp.*	16
Western larch *Larix occidentalis*	536

SENSITIVE - Trees/ Coniferous

Cascades fir *Abies amabilis*	1074
Colorado spruce *Picea pungens*	536,1164
Douglas fir *Pseudotsuga menziesii*	525, 536, 1074, 1164 1687
Eastern white pine *Pinus strobus*	536
Engelmann spruce *Picea engelmannii*	1687
Loblolly pine *Pinus taeda*	1164, 536
Lodgepole pine *Pinus contorta*	536, 525
Noble fir *Abies procera*	1687
Nordman's fir *Abies nordmanniana*	1074, 1687
Norway spruce *Picea abies*	1074, 1687
Ponderosa pine *Pinus ponderosa*	536
Scotch pine *Pinus sylvestris*	525, 1164, 536, 1074

Flourine (Con't)

SENSITIVE - Trees/Evergreen

	Reference
Serbian spruce *Picea omorika*	1074, 1687
Silver fir *Abies pectinata*	1687
White fir *Abies concolor*	1687

SENSITIVE - Shrubs

Blueberry *Vaccinium sp.*	1164
Common barberry *Berberis vulgaris*	765
Dwarf alps honeysuckle *Lonicera alpigena*	765
Dwarf mugo pine *Pinus mugo mughus*	536
St. Johnswort *Hypericum maculatum*	1010, 765
St. Johnswort *Jupericum perforatum*	765

SENSITIVE - Herbaceous

Amaranthus *Amaranthus retroflexus*	765
Annual blue grass *Poa annua*	765
Catchfly *Silene inflata*	765
Colchis (Fall crocus) *Colchicum autumale*	765
Common chickweed *Stellaria media*	765
Corn *Zea mays*	16
Fall crocus (Colchis) *Colchicum autumale*	765
Gladiolus	990, 363, 318, 886C, 16, 136, 269
Goosefoot *Chenopodium alba*	765
Goosefoot *Chenopodium murale*	765
Grape *Vivis vinifera*	765
Iris *Iris sp.*	990
Mustard *Sinapsis arvenis*	765
Oat grass *Arrhenatherum elatius*	765
Orchard grass *Dactylis glomerata*	765
Oregan grape *Vitis sp.*	363
Tulip	318

TABLE IV- 2

PLANT SPECIES SENSITIVITY LISTS

General Pollution

TOLERANT - Trees/Deciduous

	Reference
Alder *Alnus sp.*	39, 1400
Almond tree *Prunus amygdalus*	407
American beech (Red beech) *Fagus grandifolia*	39
Apple *Malus sp.*	787
Ash *Fraxinus sp.*	890Q, 39
Balsam poplar *Populus balsamifera*	890J, 886K, 889A
Birch *Betula lenta*	889A,886I,8900,1400
Box elder *Acer negundo*	886K,890L,890J, 890L,886I
Canadian poplar (Carolina poplar) *Populus canadensis*	890L
Carolina poplar (Canadian poplar) *Populus canadensis*	890L
Cherry *Prunus sp.*	890Q, 1501, 407
Eastern poplar *Populus deltoides*	886N
Elder *Sambucus sp.*	890Q
Elm *Ulmus sp.*	886K,889A,890J,890Q
European mountain ash *Sorbus aucuparia*	890Q
Flowering dogwood *Cornus florida*	890Q
Gingko (Maidenhair tree) *Gingko biloba*	1358
Goat willow *Salix caprea*	890L
Hawthorn *Crataegus sp.*	889B
Honey locust *Gleditsia triacanthos*	1976
Japanese larch *Larix leptolepsis*	787
Japanese pagoda tree *Sophora japonica*	1976
Juneberry *Amelanchier sp.*	8900
Larch *Larix sp.*	1400
London plane tree *Platanus acerifolia*	1976
Maidenhair tree (Gingko) *Gingko biloba*	1358
Oak *Quercus sp.*	889A
Oleaster (Russian olive) *Elaeagnus angustifolia*	886K,890J,890,889A
Ornamental apple *Malus floribunda*	890Q
Peach *Prunus persica*	407
Pear *Pyrus communis*	809Q
Plum *Prunus sp.*	407
Poplar *Populus sp.*	889A, 890Q
Red ash *Fraxinus pennsylvanica*	890
Red beech (American beech) *Fagus grandifolia*	39
Redhaw hawthorn *Crataegus mollis*	890Q
Russian olive (Oleaster) *Elaeagnus angustifolia*	886K,890J,890,889A
Scarlet elder *Sambucus pubens*	889B, 890L
Silverberry *Elaeagnus commutata*	890L
Tree of heaven *Ailanthus altissima*	1358

TOLERANT - Trees/ Coniferous

Arborvitae *Thuja sp.*	886N
Austrian pine *Pinus nigra*	41, 787
Cedar (Eastern red cedar) *Juniperus virginiana*	890Q
Colorado spruce *Picea pungens*	886N, 787
Eastern red cedar (Cedar) *Juniperus virginiana*	890Q
Eastern white pine *Pinus strobus*	889A
Sitka spruce *Picea sitchensis*	787
Western red cedar *Thuja plicata*	787, 890Q

General Pollution (Con't)

TOLERANT - Shrubs

	Reference
Alder buckthorn *Rhamnus frangula*	886I
Alpine currant *Ribes sp.*	890Q
Blueberry *Vaccinium sp.*	407
Common lilac *Syringa vulgaris*	886K
Hedgerow rose *Rosa sp.*	890Q
Lilac *Syringa sp.*	890L, 890Q
Mentor barberry *Berberis mentorensis*	1501, 886I, 890Q
Spindletree *Euonymus sp.*	890L
Snowberry *Symphoricarpos albus*	890L
Sweetbriar *Rosa eglantaria*	890Q
Tatarian honeysuckle *Lonicera tatarica*	890L
Viburnum *Viburnum sp.*	890Q

TOLERANT - Herbaceous

Annual bluegrass *Poa annua*	407
Barley *Hordeum sp.*	407
Bean *Phaseolus*	407
Benoite *Geum sp.*	407
Blanketflower *Gaillardia sp.*	1513
Cabbage *Brassica napolerassica*	407
Cauliflower	407
Chickweed *Cerastium triviale*	38
Chrysanthemum *Chrysanthemum*	407
Corn *Zea mays*	407
Dandelion *Taraxacum platicardum*	38
Day lily *Hemerocallis fulva*	38
Hawksbeard *Crepis japonica*	38
Onion *Allium japonica*	38
Peas *Vigna sp.*	407
Pepper	407
Pink satin petunia *Petunia sp.*	797
Potatoes *Solanum jamesii*	407
Radish *Raphanus sp.*	407
Rhubarb *Rheum rhaponticum*	407
Roth *Athyrium nipponicum*	38
Siberian pea shrub	886K, 890
Spurge *Euphorbia helioscopia*	38
Spurge *Euphorbia sieboldiana*	38
St. Johnswort *Hypericum sp.*	407
Starwort *Stellaria media*	38
Strawberry *Fragaria sp.*	407
Tickseed *Coreopsis tinctoria*	38
Wheat *Triticum aestivum*	407
Woodbine *Lonicera periclymenum*	890Q
Wormwood *Artemis vulgaris*	38

INTERMEDIATE - Trees/Deciduous

Alder *Alnus sp.*	886C, 889A

General Pollution (Con't)

INTERMEDIATE - Trees/Deciduous

	Reference
American linden (Basswood) *Tilia americana*	886, 733
Apple *Malus sp.*	1332
Apricot *Prunus armeniaca*	407
Ash *Fraxinus bungeana*	38
Ash *Fraxinus longicuspis*	38
Aspen (Hybrid poplar) *Populus sp.*	886L, 890E, 886C
Balsam poplar *Populus balsamifera*	890E, 886L
Basswood (American linden) *Tilia americana*	886, 733
Black poplar *Populus nigra*	890E
Box elder *Acer negundo*	889A
Canoe birch (White birch) *Betula papyrifera*	886L, 890E
Chestnut oak *Quercus dentata*	38
Chokecherry *Prunus virginiana*	733
Elder *Sambucus*	886C
Elm *Ulmus sp.*	889A
English oak *Quercus robor*	886N
European larch *Larix decidua*	787, 886
Fig *Ficus carica*	733
Gladbearing oak *Quercus glandbearing*	38, 886C
Grapefruit *Citrus sp.*	407
Green ash *Fraxinus pennsylvanica var. lanceolata*	890E
Hawthorn *Crataegus*	886C, 733
Hornbeam *Carpinus sp.*	886C
Hybrid poplar (Aspen) *Populus sp.*	886L, 890E, 886C
Little leaf linden *Tilia cordata*	886N
Lombardy poplar *Populus nigra var. italica*	733
Maple *Acer sp.*	889A
Mountain ash *Sorbus americana*	890E
Mulberry *Morus sp.*	886C
Norway maple *Acer platanoides*	501
Pubescent birch *Betula sp.*	886N
Red ash *Fraxinus pennsylvanica*	886N, 501, 890L
Sawtooth oak *Quercus acuta*	38
Silver maple *Acer saccharinum*	501
Tulip poplar (Yellow poplar) *Liriodendron tulipifera*	501
Walnut *Juglans sp.*	407
White birch (Canoe birch) *Betula papyrifera*	886L, 890E
Willow *Salix sp.*	886C
Yellow poplar (Tulip poplar) *Liriodendron tulipifera*	501

INTERMEDIATE - Trees/Coniferous

Arborvitae *Thuja sp.*	889A
Canadian hemlock *Tsuga canadensis*	787
Colorado spruce *Picea pungens*	733
Eastern white pine *Pinus strobus*	886N, 787
Engelmann's spruce *Picea engelmanni*	889A
False cypress *Chameocyparis sp.*	889A
Fir *Abies sp.*	787
Japanese red pine *Pinus densiflora*	38
Lodgepole pine *Pinus contorta*	889A

General Pollution (Con't)

INTERMEDIATE - Coniferous

	Reference
Norway pine (Red pine) *Pinus resinosa*	886N
Pitch pine *Pinus rigida*	733
Red pine (Norway pine) *Pinus resinosa*	886N
Serbian spruce *Picea omorika*	889A

INTERMEDIATE - Shrubs

Common lilac *Syringa vulgaris*	890J
Filbert *Corylus sp.*	890L
Forsythia *Forsythia intermedia*	733, 501
Hedgerow rose *Rosa sp.*	890E
Japanese barberry *Berberis thunbergii*	890L
Juniper *Juniperus sp.*	889A
Spirea *Spirea sp.*	733
Tatarian honeysuckle *Lonicera tatarica*	501, 890J
Weigela *Weigela florida*	501

INTERMEDIATE - Herbaceous

Ageratum *Eupatorium coelestinum*	407
Bean *Phaseolus sp.*	407
Bluegrass *Poa matsumural*	38
Carnation *Dianthus sp.*	407
Celery *Spermolepsis sp.*	407
Chrysanthenum *Chrysanthenum sp.*	407
Common plantago *Plantago major*	38
Cudweed *Gnaphalium multiceps*	38
Daisy fleabane *Erigeron strigosus*	38
Endive *Cichorium endivia*	407
Grape *Vitis vinifera*	733
Groundsel *Senecio nikoensis*	38
Heat lettuce *Lactuca sp.*	407
Knotweed *Polygonum virginianum*	38
Lucerne *Medicago sativa*	407
Maidenhair *Adiantum pedatum*	38
Nasturtium (Yellow cress) *Nasturtium indicum*	38
Oat *Danthonia sp.*	407
Onion *Alliumsp.*	407
Petunia *Petunia sp.*	407
Rape seed (Turnip) *Brassica rapa*	407
Siberian pea tree	889A, 890J, 890L
Sorrel *Rumex acetosa*	38
Sudan grasses	407
Sweet coltsfoot *Petasites japonica*	38
Turnip (Rape seed) *Brassica rapa*	407
Violet *Viola sp.*	38
Yellow cress (Nasturtium) *Nasturtium indicum*	38
Zinnias *Heliopsis elegans*	407

General Pollution (Con't)

SENSITIVE - Trees/Deciduous

	Reference
Alder *Alnus multinervis*	38
Apple (Siberian crabapple) *Malus baccata*	886L, 311
Ash *Fraxinus sp.*	889A
Beech *Fagus sp.*	889A
Birch *Betula sp.*	886I, 311, 425
Black oak *Quercus velutina*	733
Box elder *Acer negundo*	890E
Buckeye *Aesculus turbinata*	38
Catalpa *Catalpa speciosa*	311, 425
Chestnut oak *Quercus prinus*	733
Chokecherry *Prunus virginiana*	733
Elm *Ulmus sp.*	811, 425, 1501
Japanese maple *Acer palmatum*	38, 425
Judas tree *Cercis siliquastrum*	1501
Larch *Larix sp.*	890K, 311, 38, 890E
Lichen	1490
Linden *Tilia sp.*	889A
Lombardy poplar *Populus nigra var. italica*	311, 425
Mahogany *Melia japonica*	38
Mulberry *Morus microphylla*	311
Oak *Quercus sp.*	425
Orange *Citrus sp.*	727
Peach *Prunus persica*	1332, 733
Pear *Pyrus communis*	311
Pumila Arborea (Turkestan elm) *Ulmus turkestanica*	890E
Siberian crabapple (Apple) *Malus baccata*	886L, 311
Tree of heaven *Ailanthus altissima*	1501
Turkestan elm (Pumila arborea) *Ulmus turkestanica*	890E
White oak *Quercus alba*	733
White poplar *Populus alba*	38
Wild black cherry *Prunus serotina*	1332

SENSITIVE - Trees/ Coniferous

Austrian pine *Pinus nigra*	733
Colorado spruce *Picea pungens*	733
Douglas fir *Pseudotsuga menziesii*	425, 733
Eastern white pine *Pinus strobus*	733, 311
Fir *Abies sp.*	890E, 886N, 886C, 889A
Norway spruce *Picea abies*	733
Ponderosa pine *Pinus ponderosa*	311
Scotch pine *Pinus sylvestris*	733, 886K, 890J, 787, 889A
Spruce *Picea sp.*	425, 889A, 886N, 39, 890E

General Pollution (Con't)

SENSITIVE - Shrubs

	Reference
Common lilac *Syringa vulgaris*	733
Oregon holly-grape *Mahonia aquifolium*	733
Yew *Taxus sp.*	889A

SENSITIVE - Herbaceous

Aconite *Aconitum japonicum*	38
Agrimony *Agrimonia pilosa*	38
Alfalfa *Medicago sativa*	727, 311
Aster *Aster bigelobii*	311
Bachelor's button *Centaurea cyanus*	311
Barley *Hordeum vulgare*	311
Bean *Phaseolus vulgaris*	311
Bedstraw *Galium strigosum*	
Beet *Beta vulgaris*	311, 407
Bindweed *Convolvulus arvensis*	311
Bluegrass *Poa sp.*	886C
Broccoli *Brassica oleraccea*	311
Brussel sprouts *Brassica aleracea var. gemmifera*	311
Buckwheat *Fagopyrum sagittatum*	311, 1332
Careless weed *Amaranthus palmeri*	311
Carrot *Daucus carota*	311
Catbriar *Smilax racemosa*	733
Chickweed *Stellaria media*	407
Cinquefoil *Potentilla chinensis*	38
Clover *Melilotus sp.*	311
Clover *Trifoeium sp.*	311
Corn *Zea mays*	1332
Cosmos *Cosmos bipinnatus*	311
Cotton *Gossypium sp.*	311
Curly clock *Rumex crispus*	311
Endive *Cichorium endivia*	311
Fleabane *Erigeron canadensis*	311
Four o'clock *Mirabilis jalapa*	311
Galinsoga *Galinsoga parvifolia*	407
Goosefoot *Chenapodium album*	407
Green beans *Phaseolus sp.*	727
Gypsy petunia *Petunia sp.*	797
Horsetail *Equisetum arvense*	38
Huckleberry *Gaylussacia sp.*	733
Lettuce *Lactuca sativa*	311
Lettuce, prickly *Lactuca scariola*	311
Lima bean *Phaseolus limensis*	727
Mallow *Malva parvifolia*	311
Morning glory *Ipomoea*	311
Mosses *Commelina sp.*	1490
Oat *Avena sativa*	311
Okra *Hibiscus esculentus*	311
Pea *Vigna sinensis*	890K
Peanut *Arachis sp.*	727

General Pollution (Con't)

SENSITIVE - Herbaceous

	Reference
Peat tree	889A
Pepper bell, chili *Capsicum prutescens*	311
Pinto beans	727
Plantain *Plantago major*	311
Pumpkin *Cucurbita pepo*	311
Radish *Raphanus sativus*	311, 407
Ragweed *Ambrosia artemisifolia*	311
Rape seed (Turnip) *Brassica rapa*	311
Rhubarb *Rheum Rhaponticum*	311
Rye *Secale cereale*	311
Solomon's seal *Polygonatum latifolium*	38
Sorrel *Rumex sp.*	407
Soybean *Glycine max.*	311, 727
Spinach *Spinacia oleracea*	727, 311, 407
Squash *Cucurbita maxima*	311
Sunflower *Helianthus*	311
Sweet corn	727
Sweet potato *Ipomoea batatas*	311
Swiss chard *Beta vulgaris var. cicla*	311, 407
Thistle *Cirsium inconiptum*	38
Tomato *Lycopersicium esculentum*	1332, 727
Turnip (Rape seed) *Brassica rapa*	311
Velvet-weed *Gaura parvifolia*	311
Vervain *Verbena canadensis*	311
Violet *Viola sp.*	311
Wheat *Triticum sp.*	311
Wild potato *Solanum jamesii*	727
Wood nettle *Laportea bulbifera*	38
Zinnia *Zinnia elegans*	311

TABLE IV-3

PLANT SPECIES SENSITIVITY LISTS

Hydrogen Chloride

TOLERANT - Trees/deciduous

	Reference
Birch *Betula sp.*	536
Black Cherry *Prunus serotina*	536
Cherry *Prunus sp.*	886C
English walnut (Persian walnut) *Juglans regia*	886C
Maple *Acer sp.*	536
Oak *Quercus sp.*	536
Oleaster (Russian olive) *Eleagnus angustifolia*	536
Pear *Pyrus communis*	536
Persian walnut (English walnut) *Juglans regia*	886C
Red oak *Quercus borealis*	536
Russian olive (Oleaster) *Eleagnus angustifolia*	536

TOLERANT - Trees/Coniferous

Arborvitae *Thuja sp.*	536
Austrian pine *Pinus nigra*	536, 1104
Balsam fir *Abies balsamea*	536
Canadian hemlock *Tsuga canadensis*	536
Eastern white pine *Pinus strobus*	536
Jack pine *Pinus banksiana*	536
Loblolly pine *Pinus taeda*	536
Norway spruce *Picea abies*	536
Short leaf pine *Pinus echinata*	536

TOLERANT - Shrub

Yew *Taxus sp.*	536

TOLERANT - Herbaceous

Carrot *Daucus carota*	187
Grapevine *Vitis sp.*	886C

INTERMEDIATE - Trees/Deciduous

Black Cherry *Prunus serotina*	536
Black gum *Nyssa sylvatica*	536

INTERMEDIATE - Trees/ Coniferous

Jack Pine *Pinus banksiana*	536
Short leaf pine *Pinus echinata*	536

SENSITIVE - Trees/Deciduous

Apple *Malus sp.*	536
Box Elder *Acer negundo*	536
Cherry *Prunus sp.*	536
Horsechestnut *Aesculus hippocastanum*	536
Larch *Larix sp.*	536

Hydrogen Chloride (Con't)

SENSITIVE - Trees/Deciduous

	Reference
Pin oak *Quercus palustris*	536
Sassafras *Sassafras albidium*	536
Sugar maple *Acer saccharum*	536
Sweetgum *Liquidambar styraciflua*	536
Tree of heaven *Ailanthus altissima*	536

TABLE IV- 4

PLANT SPECIES SENSITIVITY LISTS

Nitrogen Dioxide

	Reference
TOLERANT - Trees/Deciduous	
Beech *Fagus sp.*	16
Gingko (Maidenhair tree) *Gingko biloba*	16
Maidenhair tree (Gingko) *Gingko biloba*	16
Oak *Quercus sp.*	16
TOLERANT - Trees/Evergreen	
Austrian pine *Pinus nigra*	16
TOLERANT - Herbaceous	
Cabbage *Brassica sp.*	16
Gladiolus	16
Onion *Allium sp.*	16
INTERMEDIATE - Trees/Evergreen	
European larch *Larix decidua*	536
SENSITIVE - Trees/Deciduous	
Apple *Malus sp.*	536
Black locust *Robinia pseudoacacia*	536
European beech *Fagus sylvatica*	536
European hornbeam *Carpinus betulus*	536
European red elder *Sambucus racemosa*	536
Gingko (Maidenhair tree) *Gingko biloba*	536
Japanese maple *Acer palmatum*	536
Large leaf linden *Tilia grandiflora*	536
Little leaf linden *Tilia cordata*	536
Maidenhair tree (Gingko) *Gingko biloba*	536
Norwary maple *Acer platanoides*	536
Pear *Pyrus communis*	536
SENSITIVE - Trees/Evergreen	
Austrian pine *Pinus nigra*	536
Colorado spruce *Picea pungens*	536
Eastern white pine *Pinus strobus*	536
White spruce *Picea glauca*	536
SENSITIVE - Shrubs	
Dwarf mugo pine *Pinus mugo mughus*	536
SENSITIVE - Herbaceous	
Barley *Hordeum sp.*	16
Begonia *Rumex sp.*	16
Carrot *Daucus carota*	16
Kidney beans *Phaseolus sp.*	16

Nitrogen Dioxide (Con't)

SENSITIVE - Herbaceous

	Reference
Lettuce *Lactuca sp.*	1849, 16
Red clover *Trifolium pratense*	16
Sweat peas *Lathyrus odoratus*	16
Tobacco *Nicotiana sp.*	16

TABLE IV- 5

PLANT SPECIES SENSITIVITY LISTS

Ozone

TOLERANT - Trees/ Coniferous

	Reference
Acacia *Acacia sp.*	181
Alder *Alnus sp.*	1164
American sycamore *Platanus occidentalis*	1074, 1164, 990
Ash *Fraxinus sp.*	181
Basswood (Linden) *Tilia sp.*	1137
Black walnut *Juglans nigra*	1164, 536
English oak *Quercus robor*	536, 1164
European mountain ash *Sorbus aucuparia*	536
European white birch *Betula pendula*	536, 1164
Fig *Ficus carica*	181
Flowering dogwood *Cornus florida*	536, 1164
Giant sequoia *Sequoia gigantea*	536
Linden (Basswood) *Tilia sp.*	1137
Little leaf linden *Tilia cordata*	1164
Maidenhair tree *Gingko biloba*	181
Norway maple *Acer platanoides*	536, 1164
Plum *Prunus sp.*	181
Red maple *Acer rubrum*	536, 1164
Red oak *Quercus borealis*	1164
Redwood *Sequoia sempervirens*	536
Shingle oak *Quercus imbricaria*	536. 1164
Sugar maple *Acer saccharum*	536, 1137
Weeping willow *Salix babylonica*	1164
White birch *Betula papyrifera*	1137

TOLERANT - Trees/Evergreen

Arborvitae *Thuja sp.*	774, 1164, 536
Balsam fir *Abies balsamea*	1137, 536, 1164, 774
Black hills spruce *Picea glauca densata*	774, 1164, 536, 1137
Colorado spruce *Picea pungens*	1137, 536, 1164, 774
Digger pine *Pinus sabiniana*	536
Douglas fir *Pseudotsuga menziesii*	774, 1137, 536, 1164
Eastern red cedar *Juniperus virginiana*	181
Jack pine *Pinus banksiana*	1074
Norway pine (Red pine) *Pinus resinosa*	1137, 1164, 774, 536
Norway spruce *Picea abies*	1137, 774, 1164, 536
Red pine (Norway pine) *Pinus resinosa*	1137, 1164, 774, 536
Singleleaf pinyon pine *Pinus monophylla*	536
Sugar pine *Pinus lambertiana*	536
Torrey pine *Pinus torreyana*	536
Virginia pine *Pinus virginiana*	1074
White fir *Abies concolor*	774, 1164, 1137
White spruce *Picea glauca*	536, 1164

TOLERANT - Shrubs

Ivy *Hedera sp.*	181

TOLERANT - Herbaceous

Bugleweed (Carpet bugle) *Ajuga sp.*	181

Ozone (Con't)

TOLERANT - Herbaceous

	Reference
California poppy *Eschscholtzia california*	181
Carpet bugle (Bugleweed) *Ajuga sp.*	181
Lady's slipper *Cypripedium sp.*	181
Leadwort *Ceratostigma plumbaginoides*	181
Petunia *Petunia sp.*	1015, 1074

INTERMEDIATE - Trees/ Coniferous

Big cone Douglas fir *Pseudotsuga macrocarpa*	536
Coulter pine *Pinus coulteri*	536
California: Incense-cedar *Libocedrus decurrens*	536
White fir *Abies concolor*	536

SENSITIVE - Trees/Deciduous

Alder *Alnus sp.*	536
American elm *Ulmus americana*	1164
American sycamore *Platanus occidentalis*	1074
Black locust *Robinia pseudoacacia*	1164, 536
Boxelder *Acer negundo*	536, 1164
California sycamore *Platanus racemosa*	1074
Catalpa *Catalpa speciosa*	1164
European larch *Larix decidua*	990, 1164, 1137, 536
Gambel oak *Quercus gambellii*	1164, 536
Green ash *Fraxinus pennsylvanica lanceolata*	536, 1164
Honeylocust *Gleditsia triacanthos*	1164, 536
Hybrid poplar *Populus sp.*	--
Japanese larch *Larix leptolepsis*	1164, 536, 77
Judas tree *Cercis siliquastrum*	536
Little leaf linden *Tilia cordata*	536
Mapleleaf mulberry (White mulberry) *Morus alba*	536
Pin oak *Quercus palustris*	536, 1164
Quaking aspen *Populus tremuloides*	536, 1164
Scarlet oak *Quercus coccinea*	1164, 536
Siberian crab apple *Malus baccata*	536, 1164
Silver maple *Acer saccharinum*	536, 1164
Sweetgum *Liquidambar styraciflua*	1164, 536
Thornless honeylocust *Gleditsia triacanthos inermis*	1074
Tulip poplar (Yellow poplar) *Liriodendron tulipifera*	990,1164,536,1074,1137
Weeping willow *Salix babylonica*	536
White ash *Fraxinus americana*	990,1137,1074,536,1164
White mulberry (Mapleleaf mulberry) *Morus alba*	536
White oak *Quercus alba*	1164, 536, 1137
Yellow poplar (Tulip poplar) *Liriodendron tulipifera*	990,1164,536,1074,1137

SENSITIVE - Trees/ Coniferous

Austrian pine *Pinus nigra*	1164, 536, 774, 1137

Ozone (Con't)

SENSITIVE - Trees/ Coniferous

	Reference
Canadian hemlock *Tsuga canadensis*	536, 1137
Eastern white pine *Pinus strobus*	536, 774, 1137, 532 990, 1164
Jack pine *Pinus banksiana*	774, 536, 1164
Jeffery pine *Pinus jeffreyi*	536
Monterey pine *Pinus radiata*	536
Pitch pine *Pinus rigida*	1164, 1135, 774, 536
Ponderosa pine *Pinus ponderosa*	536
Scotch pine *Pinus sylvestris*	774, 536, 990
Virginia pine *Pinus virginiana*	536, 774, 1137

SENSITIVE - Shrubs

Bridal wreath spirea *Spirea prunifolia*	1164
Camellia *Camelia sp.*	2
Common lilac *Syringa vulgaris*	990, 1164
Common privet *Ligustrum vulgare*	1164
Snowberry *Symphoricarpos albus*	536

SENSITIVE - Herbaceous

Aster *Aster sp.*	990
Sage *Salvia sp.*	990
Tobacco *Nicotiana sp.*	599

TABLE IV-6

PLANT SPECIES SENSITIVITY LISTS

Pan

TOLERANT - Trees/Deciduous	Reference
European larch *Larix decidua*	536
Japanese larch *Larix leptolepsis*	536
Sugar maple *Acer saccharum*	536
TOLERANT - Trees/Evergreen	
Austrian pine *Pinus nigra*	536
Canadian hemlock *Tsuga canadensis*	536
Colorado spruce *Picea pungens*	536
Eastern white pine *Pinus strobus*	536
Jack pine *Pinus banksiana*	536
Pitch pine *Pinus rigida*	536
White spruce *Picea glauca*	536
SENSITIVE - Trees/Deciduous	
Little leaf linden *Tilia cordata*	536
Tulip poplar (Yellow poplar) *Liriodendron tulipifera*	536
Yellow poplar (Tulip poplar) *Liriodendron tulipifera*	536
SENSITIVE - Herbaceous	
Aster *Aster sp.*	990
Chrysanthemum *Chrysanthemum sp.*	990
Lettuce *Lactuca sp.*	1849
Petunia *Petunia sp.*	990
Primrose *Primula sp.*	990
Sage *Salvia sp.*	990
Snapdragon *Chaenorrhinum sp.*	990

TABLE IV- 7

PLANT SPECIES SENSITIVITY LISTS

Particulates - Smoke

TOLERANT - Trees/Deciduous

	Reference
American Elm *Ulmus americana*	547
European larch *Larix decidua*	1604
Scarlet elder *Sambucus pubens*	1390

TOLERANT - Shrub

Cranberry *Vaccinium sp.*	187

TOLERANT - Herbaceous

Knotweed *Polygonum cilinode*	1390

INTERMEDIATE - Trees/Deciduous

Alder *Alnus sp.*	1604
American beech (Red beech) *Fagus grandifolia*	1604
American hornbeam *Carpinus caroliniana*	1604
Birch *Betula sp.*	1604
English oak *Quercus robor (formerly called penduculata)*	1604
Maple *Acer sp.*	1604
Poplar *Populus sp.*	1604
Raceme oak *Quercus racemosa*	1604
Red beech (American beech) *Fagus grandifolia*	1604
Red oak *Quercus borealis*	1604
White alder *Alnus rhombifolia*	1604

INTERMEDIATE - Trees/ Coniferous

Austrian Pine *Pinus nigra*	1604
Eastern white pine *Pinus strobus*	1604
Scotch pine *Pinus sylvestris*	1604

SENSITIVE -Trees/Deciduous

Quaking aspen *Populus tremuloides*	1390
Single-seeded hawthorne *Crataegus monogyna*	1675

SENSITIVE - Trees/Coniferous

Black Spruce *Picea mariana*	1390
Eastern white pine *Pinus strobus*	1390
Fir *Abies sp.*	1604
Norway spruce *Picea abies (excelsa)*	1604
White spruce *Picea glauca*	1390

SENSITIVE - Herbaceous

Annual bluegrass *Poa annua*	269

TABLE IV-8

PLANT SPECIES SENSITIVITY LISTS

Sulfur Dioxide

TOLERANT - Trees/Deciduous

	Reference
American sycamore *Platanus occidentalis*	1164
Ash *Fraxinus sp.*	886C
Basswood (Linden) *Tilia sp.*	369
Beech *Fagus sp.*	1187, 886C
Birch *Betula sp.*	64, 523, 1187
Black gum *Nyssa sylvatica*	1169, 536
Black locust *Robinia pseudoacacia*	536
Cottonwood (Eastern poplar) *Populus deltoides*	1164, 536
Eastern poplar (Cottonwood) *Populus deltoides*	1164, 536
English oak *Quercus robor*	1164, 536
European ash *Fraxinus excelsior*	369
European beech *Fagus sylvatica*	536
European hornbeam *Carpinus betulus*	536
European mountain ash *Sorbus aucuparia*	369
Flowering dogwood *Cornus florida*	1164, 536
Gingko (Maidenhair tree) *Gingko biloba*	1164, 369
Green ash *Fraxinus pennsylvanica lanceolata*	536, 1164
Hedge maple *Acer campestre*	536, 1164
Hornbeam *Carpinus sp.*	1187
Larch *Larix sp.*	44
Linden (Basswood) *Tilia sp.*	369
Maidenhair tree (Gingko) *Gingko biloba*	1164, 369
Mountain maple *Acer spicatum*	1164
Oak *Quercus sp.*	44
Oriental plane tree *Platanus orientalis*	1164
Persian walnut *Juglans regia*	886C
Pin oak *Quercus palustris*	1164
Poplar *Populus sp.*	369
Red berried elder *Sambucus pubescens*	1074
Red maple *Acer rubrum*	536, 1164
Red oak *Quercus borealis*	1164, 44
Smooth elm *Ulmus glabra*	369
Sourwood *Oxydendrum arboreum*	369
Sugar maple *Acer saccharum*	1164
Tulip poplar (Yellow poplar) *Liriodendron tulipifera*	16, 1164, 369
White ash *Fraxinus americana*	138
Willow *Salix sp.*	369
Yellow poplar (Tulip poplar) *Liriodendron tulipifera*	16, 1164, 369

TOLERANT - Trees/ Coniferous

Arborvitae *Thuja occidentalis*	1164
Austrian pine *Pinus nigra*	525, 1164, 536
Canadian hemlock *Tsuga canadensis*	1074
English holly *Ilex aquifolium*	1164, 536
Lawson false cypress *Chamaecyparis lawsoniana*	536
Spruce *Picea sp.*	886C
Western red cedar *Thuja plicata*	1164
White spruce *Picea glauca*	1164

Sulfur Dioxide (Con't)

TOLERANT - Shrubs

	Reference
Dwarf mugo pine *Pinus mugo mughus*	536
Juniper *Juniperus sp.*	1164, 536

TOLERANT - Herbaceous

Alfalfa *Medicago sativa*	886C
Corn *Zea mays*	16
Fringed bindweed *Polygonum cilinode*	1074
Galleta *Hilaria jamesii*	1365
Grama grass *Bouteloua barbata*	1365
Heliotrope *Heliotropium sp.*	886C
Meadow fescue *Festuca elatior*	136
Oats *Avena sp.*	886C
Orchard grass *Dactilus glomerada*	136
Primrose *Primula sp.*	886C
Sweetpea *Lathyrus odoratus*	886C
Woodwaxen	886C

INTERMEDIATE - Trees/Deciduous

Apple *Malus sp.*	16
Apricot *Prunus armeniaca*	16
Balsam poplar *Populus balsamifera*	1164, 536
Bigtooth aspen *Populus grandidentata*	1164
Norway maple *Acer platanoides*	1164

INTERMEDIATE - Trees/Coniferous

Balsam fir *Abies balsamea*	536, 1164, 525
Douglas fir *Pseudotsuga menziesii*	1164, 525, 536
Lodgepole pine *Pinus contorta*	536, 525
Scotch pine *Pinus sylvestris*	1164
Silver fir *Abies pectinata*	536

INTERMEDIATE - Shrubs

Rose *Rosa sp.*	16

INTERMEDIATE - Herbaceous

Gladiolus	16
Cotton *Gossypium sp.*	16
Iris *Iris sp.*	16

SENSITIVE - Trees/Deciduous

Alder *Alnus*	119, 732
American elm *Ulmus americana*	1164
American sycamore *Platanus occidentalis*	1164
Apple *Malus sp.*	1164

Sulfur Dioxide (Con't)

SENSITIVE - Trees/Deciduous

	Reference
Aspen (Poplar) *Populus sp.*	732, 1187
Birch *Betula sp.*	1164, 1119
Blueberry elder *Sambucus coerulea*	732
Canoe birch (White birch) *Betula papyrifera*	732
Catalpa *Catalpa speciosa*	1164
Cherry *Prunus sp.*	732
Chokecherry *Prunus virginiana*	938
English walnut (Persian walnut) *Juglans regia*	1164
European mountain ash *Sorbus aucuparia*	732, 1187
Horse chestnut *Aesculus hippocastanum*	44
Hornbeam *Carpinus sp.*	44
Larch *Larix sp.*	732, 1164
Lombardy poplar *Populus nigra var. italica*	1164
Maple *Acer sp.*	1187
Mazzard cherry *Prunus avium*	886C
Mountain ash *Sorbus americana*	1164
Mountain maple *Acer spicatum*	44
Narrowleaf cottonwood *Populus angustifolia*	1365
Pear *Pyrus communis*	1164
Persian walnut (English walnut) *Juglans regia*	1164
Poplar (Aspen) *Populus sp.*	732, 1187
Quaking aspen *Populus tremuloides*	1164, 119
Scarlet hawthorn *Crataegus oxyacantha*	990
Serviceberry *Amelanchier sp.*	1164
Texas mulberry *Morus microphylla*	1164
Utah serviceberry *Amelanchier utahensis*	1164
White ash *Fraxinus americana*	773
White birch (Canoe birch) *Betula papyrifera*	732
Willow *Salix sp.*	1164, 732

SENSITIVE - Trees/Coniferous

Black spruce *Picea mariana*	1164
Canadian hemlock *Tsuga canadensis*	1164
Douglas fir *Pseudotsuga menziesii*	990
Eastern white pine *Pinus strobus*	990, 1164, 1074, 563,732,773,119
Engelman's spruce *Picea engelmannii*	1164
Fir *Abies sp.*	119
Jack pine *Pinus banksiana*	1164
Mountain hemlock *Tsuga mertensiana*	1164
Norway pine (Red pine) *Pinus resinosa*	16
Ponderosa pine *Pinus ponderosa*	1164, 1007
Red pine (Norway pine) *Pinus resinosa*	16
Scotch pine *Pinus sylvestris*	1074, 525
Sitka spruce *Picea sitchensis*	732
Virginia pine *Pinus virginiana*	773
Western red cedar *Thuja plicata*	1074
Western white pine *Pinus monticola*	1164

Sulfur Dioxide (Con't)

SENSITIVE - Shrubs

	Reference
Mountain laurel *Kalmia latifolia*	1164
Ninebark *Physocarpus capitatus*	1164
Snowberry *Symphoricarpos aerophilus*	1365
Wild rose *Rosa woodsii*	1365

SENSITIVE - Herbaceous

Alfalfa *Medicago sativa*	938, 732
Begonia *Rumex venosus*	990, 1009
Buckwheat *Fagopyrum sp.*	16
Celery *Spermolepsis sp.*	16
Cotton *Gossypium sp.*	16
Cucumber *Sicyos angulatus*	16
Eggplant *Solanum melongena*	16
Evening primrose *Oenothera sp.*	1365
Geranium *Geranium*	16
Globe mallow *Sphaeralcea munroana*	1365
Goosefoot *Chenopodium ofrenonti*	1365
Grape *Vitis sp.*	938
Hound's tongue *Cynoglossum officinale*	1365
Hungarian brome *Bromus inpermis*	136
Indian rice grass *Oryzopsis hymenoides*	1365
Lettuce *Lactuca sp.*	1844
Locoweed *Astragalus utahensis*	1365
Lucerne *Medicago sativa*	1007
Petunia *Petunia sp.*	1009
Potato *Solanum tuberosum*	1007
Red clover *Trifolium pratense*	136
Scarlet Gilia *Gilia agregata*	1365
Squash *Cucurbita sp.*	938
Sunflower *Helianthus sp.*	886C
Sweet clover *Melilotus sp.*	732, 16
Tobacco *Nicotiana sp.*	16
Vervain *Verbena sp.*	990
Violet *Viola sp.*	990
Wheat *Triticum aestivum*	1007

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APPENDICES - A. Conversion Factors

TABLE A-1

General SI *(System Internationale)* Conversion Tables

SI BASE UNITS

Quantity	Name of unit	Unit symbol	Quantity	Name of unit	Unit symbol
length	metre	m	electric current	ampere	A
			thermodynamic temperature	kelvin	K
mass	kilogram	kg	luminous intensity	candela	cd
time	second	s	amount of	mole	mol

TABLE A-2

APPROVED NUMERICAL PREFIXES				
Exponential Expression	Decimal Equivalent	Prefix	Phonic	Symbol
10^{12}	1 000 000 000 000	tera	ter' a	T
10^{9}	1 000 000 000	giga	ji' ga	G
10^{6}	1 000 000	mega	meg' a	M*
10^{3}	1 000	kilo	kil' o	k*
10^{2}	100	hecto	hek' to	n
10	10	deka	dek' a	da
10^{-1}	0.1	deci	des i	d
10^{-2}	0.01	centi	sen' ti	c*
10^{-3}	0.001	milli	mil' i	m*
10^{-6}	0.000 001	micro	mi' kro	u*
10^{-9}	0.000 000 001	nano	nan' o	n
10^{-12}	0.000 000 000 001	pico	pe' ko	p
10^{-15}	0.000 000 000 000 001	femto	fem' to	f
10^{-18}	0.000 000 000 000 000 001	atto	at' to	a

* most commonly used units

TABLE A-3

Common Metric Conversions
For Consideration of Air Pollution

AIR QUALITY DATA (25°C; 760 mm Hg)
ppm SO_2 x 2620 = µg/m^3SO_2 (Sulfur Dioxide)
ppm CO x 1150 = µg/m^{3}CO (Carbon Monoxide)
ppm CO_x x 1.15 = mg/m^{3}CO (Carbon Monoxide)
ppm CO_2 x 1800 = µg/m^3CO_2 (Carbon Dioxide)
ppm CO_2 x 1.8 = mg/m^3CO_2 (Carbon Dioxide)
ppm NO x 1230 = µg/m^{3}NO (Nitrogen Oxide)
ppm NO_2 x 1880 = µg/m^3NO_2 (Nitrogen Dioxide)
ppm O_3 x 1960 = µg/m^3O_3 (Ozone)
ppm CH_4 x 655 = µg/m^3CH_4 (Methane)
ppm CH_4 x .655 = mg/m^3CH_4 (Methane)
ppm CH_3SH x 2000 = µg/m^3CH_3SH (Methyl Mercaptan)
ppm C_3H_8 x 1800 = µg/m^3C_3H_8 (Propane)
ppm C_3H_8 x 1.8 = mg/m^3C_3H_8 (Propane)
ppm F^- x 790 = µg/m^3F^- (Fluoride)
ppm H_2S x 1400 = µg/m^3H_2S (Hydrogen Sulfide)
ppm NH_3 x 696 = µg/m^3NH_3 (Ammonia)
ppm HCHO x 1230 = µg/m^{3}HCHO (Formaldehyde)

TABLE A-4

To convert from	To	Multiply by
Ppm by volume (20°C)	Milligrams/cu m	$\frac{M^*}{24.04}$
	Micrograms/cu m	$\frac{M^*}{0.02404}$
	Micrograms/liter	$\frac{M^*}{24.04}$
	Ppm by weight	$\frac{M^*}{28.8}$
	Pounds/cu ft	$\frac{M^*}{385.1 \times 10^6}$
Ppm by weight	Milligrams/cu m	1.198
	Micrograms/cu m	1.198×10^3
	Micrograms/liter	1.198
	Ppm by volume (20°C)	$\frac{28.8}{M^*}$
	Pounds/cu ft	7.48×10^{-6}
Pounds/cu ft	Milligrams/cu m	16.018×10^6
	Micrograms/cu m	16.018×10^9
	Micrograms/liter	16.018×10^6
	Ppm by volume (20°C)	$\frac{385.1 \times 10^6}{M^*}$
	Ppm by weight	133.7×10^3
	PARTICLE COUNT	
No./cu m	No./liter	0.001
	No./cu cm	1.0×10^{-6}
	No./cu ft	28.317×10^{-3}
No./liter	No./cu m	1000.0
	No./cu cm	0.001
	No./cu ft	28.316
No./cu cm	No./cu m	1.0×10^6
	No./liter	1000.0
	No./cu ft	28.316×10^3
No./cu ft	No./cu m	35.314
	No./liter	35.315×10^{-3}
	No./cu cm	35.314×10^{-6}

* M = Molecular Weight

TABLE A-4 (Con't)

To convert from	To	Multiply by
	DUSTFALL	
Tons/sq mile	Pounds/acre	3.125
	Pounds/1000 sq ft	0.07174
	Grams/sq m	0.3503
	Kilograms/sq km	350.3
	Milligrams/sq m	350.3
	Milligrams/sq cm	0.03503
	Grams/sq ft	0.03254
Pounds/acre	Tons/sq mile	0.32
	Pounds/1000 sq ft	0.023
	Grams/sq m	0.1121
	Kilograms/sq km	112.1
	Milligrams/sq m	112.1
	Milligrams/sq cm	0.01121
	Grams/sq ft	0.0104
Pounds/1000 sq ft	Tons/sq mile	13.94
	Pounds/acre	43.56
	Grams/sq m	4.882
	Kilograms/sq km	4882.4
	Milligrams/sq m	4882.4
	Milligrams/sq cm	0.4882
	Grams/sq ft	0.4536
Grams/sq m	Tons/sq mile	2.855
	Pounds/acre	8.921
	Pounds/1000 sq ft	0.2048
	Kilograms/sq km	1000.
	Milligrams/sq m	1000.
	Milligrams/sq cm	0.1
	Grams/sq ft	0.0929
Grams/cu m	Milligrams/cu m	1000.0
	Grams/cu ft	0.02832
	Micrograms/cu m	1.0×10^{6}
	Micrograms/cu ft	28.317×10^{3}
	Pounds/1000 cu ft	0.06243
Micrograms/cu m	Milligrams/cu m	0.001
	Grams/cu ft	28.317×10^{-9}
	Grams/cu m	1.0×10^{-6}
	Micrograms/cu ft	0.02832
	Pounds/1000 cu ft	62.43×10^{-9}
Micrograms/cu ft	Milligrams/cu m	35.314×10^{-3}
	Grams/cu ft	1.0×10^{-6}
	Grams/cu m	35.314×10^{-6}
	Micrograms/cu m	35.314
	Pounds/1000 cu ft	2.2046×10^{-6}

TABLE A-4 (Con't)

To convert from	To	Multiply by
Pounds/1000 cu ft	Milligrams/cu m	16.018×10^3
	Grams/cu ft	0.35314
	Micrograms/cu m	16.018×10^5
	Grams/ cu m	16.018
	Micrograms/cu ft	353.14×10^3
	ATMOSPHERIC GASES	
Milligrams/cu m	Micrograms/cu m	1000.0
	Micrograms/liter	1.0
	Ppm by volume (20°C)	$\frac{24.04}{M}$
	Ppm by weight	0.8347
	Pounds/cu ft	62.43×10^{-9}
Micrograms/cu m	Milligrams/cu m	0.001
	Micrograms/liter	0.001
	Ppm by volume (20°C)	$\frac{0.02404}{M}$
	Ppm by weight	834.7×10^{-6}
	Pounds/cu ft	62.43×10^{-12}
Micrograms/liter	Milligrams/cu m	1.0
	Micrograms/cu m	1000.0
	Ppm by volume (20°C)	$\frac{24.04}{M}$
	Ppm by weight	0.8347
	Pounds/cu ft	62.43×10^{-9}
Kilograms/sq km	Tons/sq mile	2.855×10^{-3}
	Pounds/acre	8.921×10^{-3}
	Pounds/1000 sq ft	204.8×10^{-6}
	Grams/sq m	0.001
	Milligrams/sq m	1.0
	Milligrams/sq cm	0.0001
	Grams/sq ft	92.9×10^{-6}
Milligrams/sq m	Tons/sq mile	2.855×10^{-3}
	Pounds/acre	8.921×10^{-3}
	Pounds/1000 sq ft	204.8×10^{-6}
	Grams/sq m	0.001
	Kilograms/sq km	1.0
	Milligrams/sq cm	0.0001
	Grams/sq ft	92.9×10^{-6}

TABLE A-4 (Con't)

To convert from	To	Multiply by
Milligrams/sq cm	Tons/sq mile	28.55
	Pounds/acre	89.21
	Pounds/1000 sq ft	2.048
	Grams/sq m	10.0
	Kilograms/sq km	10.0 x 10^3
	Milligrams/sq m	10.0 x 10^3
	Grams/sq ft	0.929
Grams/sq ft	Tons/sq mile	30.73
	Pounds/acre	96.154
	Pounds/1000 sq ft	2.204
	Grams/sq m	10.764
	Kilograms/sq km	10.764 x 10^3
	Milligrams/sq m	10.764 x 10^3
	Milligrams/sq cm	1.0764
	AIRBORNE PARTICULATE MATTER	
Milligrams/cu m	Grams/cu ft	283.2 x 10^{-6}
	Grams/cu m	0.001
	Micrograms/cu m	1000.0
	Micrograms/cu ft	28.52
	Pounds/1000 cu ft	62.43 x 10^{-6}
Grams/cu ft	Milligrams/cu m	35.3145 x 10^3
	Grams/cu m	35.314
	Micrograms/cu m	35.314 x 10^6
	Micrograms/cu ft	1.0 x 10^6
	Pounds/1000 cu ft	2.2046

TABLE A-5

LENGTH

UNITS	SYMBOL	METERS
Angstrom	A	1×10^{-10}
Millimicron	mμ	1×10^{-9}
Micron	μ	.000001
Millimeter	mm	.001
Centimeter	cm	.01
Decimeter	dm	.10
Meter	m	1.0
Dekameter	dkm	10.
Hectometer	hm	100.
Kilometer	km	1000.

WEIGHT

UNITS	SYMBOL	GRAMS
Microgram	μg.	.000001
Milligram	mg.	.001
Centigram	cg.	.01
Decigram	dg.	.10
Gram	g.	1.0
Dekagram	dkg.	10.
Hectogram	hg.	100.
Kilogram	kg.	1000.

VOLUME

UNITS	SYMBOL	LITERS
Microliter	μl.	.000001
Milliliter	ml.	.001
Centiliter	cl.	.01
Deciliter	dl.	.10
Liter	l.	1.0
Dekaliter	dkl.	10.0
Hectoliter	hl.	100.0
Kiloliter	kl.	1000.0

TABLE A-6

CONVERSION TABLES

LENGTH

UNITS	CENTIMETERS	METERS	KILOMETERS	INCHES	FEET
Centimeter	1.00	.01	.00001	.39370	.032808
Meter	100.00	1.00	.001	39.370	3.2808
Kilometer	100000.	1000.00	1.00	39370.	3280.8
Inch	2.54	.02540	.000025	1.00	.08333
Foot	30.4801	.304801	.000305	12.00	1.00

1 Angstrom = .0001 Microns = 1 x 10^{-8} Centimeters = 3.937 x 10^{-9} Inches

1 Micron = 1 x 10^{4} Angstroms = 1 x 10^{-4} Centimeters = 3.397 x 10^{-5} Inches

1 Kilometer = .62137 Mile   1 Mile (U.S) = 1.60935 Kilometers

MASS & WEIGHT

UNITS	GRAMS	GRAINS AVOIR.	DRAMS AVOIR.	OUNCES AVOIR.	OUNCES TROY
Milligram	.001	.015432	.000564	.0000353	.0000322
Gram	1.00	15.43236	.564383	.0352740	.0321507
Kilogram	1000.	15432.36	564.383	35.2740	32.1507
Dram (Av.)	1.771845	27.34375	1.00	.0625	.056966
Ounce (Av.)	28.3495	437.5	16.00	1.00	.911458
Pound (Av.)	453.5924	7000.	256.00	16.00	14.5833
Ounce (Tr.)	31.1035	480.00	17.55428	1.09714	1.00

1 Cu. Ft. Water at 60°F = 62.37 Lbs. Av. / 1 Gal.(U.S.)Water at 62°F = 8.337 Lbs. Av.

VOLUME & CAPACITY

UNITS	LITERS	FL.OUNCE (U.S.)	LIQ.PINTS (U.S.)	CUBIC CENTIMETERS	CUBIC INCHES
Milliliter	.001	.0338147	.002113	1.00003	.061025
Liter	1.00	33.8147	2.1134	1000.03	61.025
Cu. Cm.(cc)	.001	.0338147	.002113	1.00	.061023
Cu. Inch	.0163867	.554113	.034632	16.3872	1.00
Fl. Dram(U.S.)	.003696	.125	.007813	3.6967	.225586
Fl. Oz.(U.S.)	.0295729	1.00	.0625	29.5737	1.80469
Liq. Pint(U.S.)	.473167	16.00	1.00	473.179	28.875
Liq. Gal.(U.S.)	3.7853	128.00	8.00	3785.43	231.00

1 Gal. (U.S.) = .83268 Gals.(British) / 1 Gal. (British) = 1.20094 Gals. (U.S.)

1 Minim = .0020833 Oz.(U.S.Fl.) = .016667 Dram (U.S.Fl.) = .061610 Ml. = .061612 cc.

AREA

UNITS	SQUARE CENTIMETERS	SQUARE INCHES
Sq. Cm.	1.00	.1550
Sq. Meter	10000.00	1550.00
Sq. Inch	6.451626	1.00
Sq. Foot	929.0341	144.00

PRESSURE

1 Atmosphere = 14.696 lbs./sq.in.

1 Atmosphere = 1.01325 x 10^{6} dynes/sq.cm.

1 Atmosphere = 760.00 mm. of mercury at 0°C

1 Cm. of Mercury at 0°C = .013158 atmospheres

APPENDICES - B. Abstraction Guidelines

COMSIS CORPORATION - OPEN SPACE STUDY

Forms

ABSTRACT INVENTORY NO.

CITATION

POLLUTANT(S)	**LOCATION**	**VEGETATION**	**SOIL TYPE**	**MISCELLANEOUS INFORMATION**

EMISSION	**SINK**	**LANGUAGE**	**NOs.**	**TABLES**	**FIGURES**

ABSTRACT NO.

SOURCE(S)	**LOCATION OF DOCUMENT**

NAME

DATE

COMSIS CORPORATION - OPEN SPACE STUDY

INVENTORY CATEGORIES

- Pollutants
- Location
- Vegetation
- Soil Type

POLLUTANTS

I. Particulates (aerosols)

A. Solid

1. nonviable

trace metals: aluminum (Al), calcium (Ca), silicon (Si), cadmium (Cd), magnesium (Mg), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), sodium (Na), tin (Sn), zinc (Zn), vanadium (V), beryllium (Be); asbestos, carbon, flyash, dust, soot.

2. viable

pollen, bacterial cells, bacterial spores, fungal spores, virus particles

B. Liquid

sulfate, sulfite, nitrate, nitrite, organic [hydrocarbons(HC), acids, bases, phenols].

II. Gases

A. Primary (released directly into atmosphere)

1. inorganic

a. oxides

1). nitrogen[(NO_x),nitrogen dioxide (NO_2), nitric oxide (NO), nitrous oxide (N_2O)]

2). sulfur [sulfur dioxide (SO_2)]

3). carbon [carbon monoxide (CO), carbon dioxide (CO_2)]

b. halogens

1). fluorine (F_2), fluoride (F)

2). chlorine (Cl_2), chloride (Cl)

II. A. 1. (Con't)

- c. other
  - 1). hydrogen sulfide (H_2S)
  - 2). ammonia (NH_3)

2. organic
   - a. hydrocarbons (HC)

     e.g. alkanes, alkenes, acetylenes, aliphatic, alicyclic, aromatic, methane, terpenes, ethylene, polynuclear hydrocarbons, benzo (a) pyrene, olefins

   - b. aldehydes and ketones

     e.g. formaldehyde

   - c. halocarbons (chlorofluorocarbons)
     - 1). fluorocarbons
     - 2). chlorocarbons

   - d. mercaptans

B. Secondary (synthesized in the atmosphere)
1. ozone (O_3)
2. peroxyacyl nitrates
   - a. peroxyacetyl nitrate (PAN)
   - b. peroxyproprionyl nitrate (PPN)
   - c. peroxybutyryl nitrate (PBN)
   - d. peroxyisobutyrylnitrate (Piso BN)

LOCATION

1. Urban
2. Rural (farm, forest, wetlands, field, etc.)
3. Controlled Environment (greenhouse, growth chamber, etc.)
4. Other

VEGETATION

1. Agriculture
2. Tree
3. Shrub
4. Herb
5. Other

SOIL TYPE

1. Natural (forest, field, etc.)
2. Disturbed (fertilized, top soil removed, sand & gravel, roadside, synthetic, city street, etc.)
3. Other

Strategies

Computerized literature searches were conducted in six separate federal agency files. This source of information consists of computerized bibliographic files of the cataloging and indexing records of various library or private bibliographic sources. Such records contain abstracts as well. In the case of this project, the following files were searched by developing a specific program compatible with each file.

APTIC - The Air Pollution Technical Information Center (Environmental Protection Agency)

CAIN - The National Agricultural Library Data Base (Department of Agriculture)

DATRIX - The University Microfilm System

DDC - The Defense Document Center (Department of Defense)

NTIS - The National Technical Information Service

HRB - The Highway Research Board (National Academy of Sciences)

In addition, manual searches were undertaken of two files created by Dr. Leon S. Dochinger and his colleagues at the U.S. Forest Service, Northeastern Forest Experiment Station, and Dr. William H. Smith of the Yale University School of Forestry and Environmental Sciences.

Although each computerized search in the different files requires a customized search strategy, a generalized program may be used as an example of the logic which we utilized in attempting to insure that we consider all of the pertinent and important literature. Therefore, as an example, the following search strategy is given using the CAIN file as a base.

The search strategy to enter CAIN is diagrammed on the next page. Prior to initiating a search on a computer typewriter, the searcher will have to analyze the search topic, in this case "the ability of vegetation, soil and water to remove pollutants from the atmosphere". The study involves becoming thoroughly acquainted with the vocabulary used in the literature of this subject matter. This is necessary because entering a computerized file (data base) of tens of thousands of citations requires asking the computer for information on as specific questions as possible.

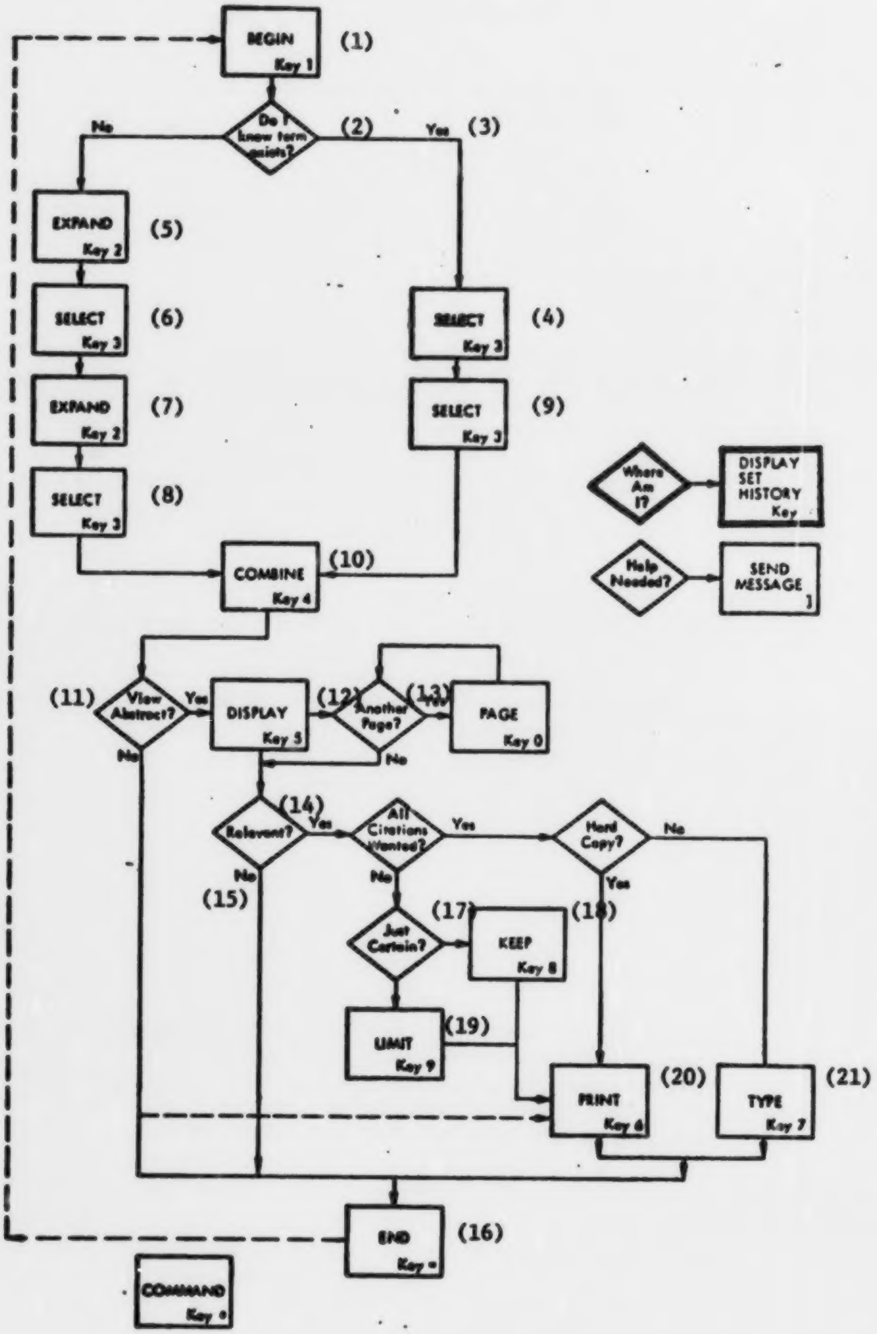
Therefore, at the time the computer is activated and given the command BEGIN (1), the searcher must be familiar with the specific subject matter to be received from the search strategy. Initially, the computer asks if the searcher knows the vocabulary which describes the sought category of information. (DO I KNOW TERM EXISTS?) (2) In our diagram, all questions the computer asks of its users are presented in diamond shaped enclosures. This is the standard notation for questions in diagrams of computer strategies. Familiarity with the pertinent vocabulary allows the searcher to answer YES (3) and proceed along that path to the next command SELECT (4).

However, in order to verify that the particular selection of search words is correct, the path of both YES and NO should be followed. The command EXPAND (5) refers to opening the data base. The computer is given an index term, in this case "pollute", and in response, the computer T.V. screen displays words arranged in alphabetical order above and below "pollute" in the computer dictionary. It also shows the number of citations in the file which contain these key words as shown below.

0.	pollumene	1
1.	pollut	0
2.	pollutans	1
3.	pollutant	61
4.	pollutants	276
5.	pollutantsemitted	1
6.	pollute	5
7.	polluted	122
8.	polluter	7
9.	polluters	4
10.	pollution	1
11.	pollutin	1
12.	polluting	30
13.	pollutio	2
14.	pollution	4407

It is evident from this expansion that the computer dictionary contains additional words dealing with pollution. Since the search strategy is to focus on all of them, it accordingly asks

FIGURE B-1
CAIN Search Strategy For
Bibliography Retrieval


BEGIN
Key 1
(1)
Do I know term exists?
(2)
No
Yes
(3)
EXPAND
Key 2
(5)
SELECT
Key 3
(6)
EXPAND
Key 2
(7)
SELECT
Key 3
(8)
SELECT
Key 3
(4)
SELECT
Key 3
(9)
Where Am I?
DISPLAY SET HISTORY
Key
Help Needed?
SEND MESSAGE
]
COMBINE
Key 4
(10)
(11)
View Abstract?
Yes
No
DISPLAY
Key 5
(12)
Another Page?
(13)
Yes
No
PAGE
Key 0
(14)
Relevant?
Yes
No
(15)
All Citations Wanted?
Yes
No
Hard Copy?
No
Yes
(17)
Just Certain?
KEEP
Key 8
(18)
LIMIT
Key 9
(19)
PRINT
Key 6
(20)
TYPE
Key 7
(21)
END
Key =
(16)
COMMAND
Key =

the computer to continue the expansion until the root "pollute" is outside the group of relevant words. For example:

```
      .
      .
32.   pollutionl   ----      1
33.   pollutions   ----     22
      .
      .
36.   polmass ------         1
37.   polmat -------         1
```

From this list, the searcher will SELECT (6) the term "pollution" because it has the most citations associated with it and therefore offers the greatest potential of obtaining the largest number of relevant articles. The second EXPAND (7) and SELECT (8) commands refer to the same process for another word such as AIR. The aim of this search is to retrieve word combinations such as AIR POLLUTION. For the latter, 5 citations were indicated, for the former, 3131. The word AIR was SELECT(ed) (8).

In following the YES path, the searcher SELECT(ed) (4) words which were relevant based on the studies prior to sitting at the computer terminal (i.e. soil, water, environment, atmosphere, sink, aerosol, etc.). The computer was asked how many citations the file contained relative to these words. A sample of the response follows:

```
soil          21350

soils         12758

atmosphere      972

sinks            41

flora          2887

green belt        5

forest        21022
```

In addition, words may be SELECT(ed) (9) in what is known as a "right hand truncation" search and a "field search". In the first case, the computer is given the root of a word followed by a question mark (?). The computer then prints out the total number of citations containing the root of that word with any suffix.

i.e.   environment ? ------ 7818 (includes -ments,
                                          -mental, -mentalist)

In a field search all the words both in the title and abstract, are searched.

i.e. mathematical (F) models - - - - 418

These two aspects of the CAIN search strategy classify it as a broad search and distinguish it from the narrower and exclusive title search of the DATRIX system (to be discussed subsequently).

The COMBINE (10) command refers to formulation of one search statement that combines all the previous words asked for and provides the total number of citations containing all these words. The number obtained was 57137. At this point in the computer search, the searcher has the number of papers listed in the CAIN bibliography having at least one word that is in the subject of interest. This number, therefore, represents the potential number of useful articles we could conceivably retrieve. However, the above words have not been linked with the word "pollution" and as a result many of the numbers refer to articles dealing with subjects such as:

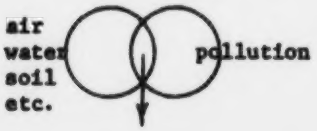
The best soil in which to grow white pine seedlings

Layers of the atmosphere

Kitchen sinks in home economics departments

The flora of Kentucky

We are only interested in the articles containing these words as they relate to pollution. So our search strategy calls for a step to COMBINE (10) which connects the descriptive words to the word pollution by the word "and". The resulting effect is illustrated in a Venn diagram.



The search requests only the articles containing combinations of both words

The number of such combinations was given as 424.

All that remains is to request the computer to print one or more of these 424 citations and/or to ask for a listing of all of them. If the searcher wishes to VIEW ABSTRACT(s) (11) of the citations, the searcher may request the computer to DISPLAY (12) the first six citations and abstracts in the file that met the above criteria (i.e., contained a combination of words such as "soil pollution"). These samples are then followed by the computer question ANOTHER PAGE (13) which asks whether the searcher would like to see another set of sample citations and abstracts. Subsequent to this review the computer asks if it is RELEVANT (14). If it is NO(t) (15), it means the searcher does not wish to obtain the citations in the file presumably because they do not contain the information initially sought. In this case, the searcher would END (16) access to the computer. But these sample citations were RELEVANT and the searcher was then asked if a listing of all 424 was required. If all are not required, a request may be made to receive (JUST CERTAIN (ones)) (17). For example, just the first, fifth and seventh citations could be kept by entering those numbers following the KEEP (18) command. (The LIMIT (19) command allows one to pick only those articles written in a particular language or year.) The PRINT COMMAND (20) asks the computer to immediately print out a list of all or whichever citations wanted on the computer typewriter. This is more expensive than receiving a printout of the citations by mail approximately a week later. The TYPE (2) command allows for this option. Terminating access to the computer is called for by the END (16) command.

ADDENDUM - Water as a Sink/Source

Based on the present literature search, very limited material was found. However, all these articles found supported the importance of water as a sink for pollutants. Those which we felt were of any relevance are presented here.

Air contaminants significantly effect water quality. Studies conducted by Bachmann and Lokey (1976)* on the trace element balances in Lake Michigan indicate that the atmosphere contributes over half of the total input (of copper, manganese and lead) to the lake. The data obtained in that study on the lead input in the southern portion of the lake, showed that more than 90% is from the atmosphere.

Air contaminants in addition to trace metals such as airborne acids, nutrients, and toxic organics (including industrial chemicals and pesticides) can be transported to lakes, streams, and marine environments. For example, Bachmann and Lokey estimated that 50% of the total input of polychlorinated biphenyls (PCB) to Lake Michigan was introduced by the atmosphere.

The amount of atmospheric inputs varies according to anthropogenic conditions and natural elements. For instance, the sources of atmospheric nutrients have not been completely identified. However, these nutrients may be introduced into the air by windblown agricultural fertilizers or from industrial activities and fuel combustion processes.

One mechanism for the transfer of airborne particulates into aquatic habitats is by precipitation. According to Bachmann and Lokey, the trace metal concentrations in rainfall generally equal or exceed the concentrations in surface waters of the United States.

A second mechanism for delivering substances to an aquatic environment is storm-water runoff of contaminants deposited from the air on to the land adjacent to the body of water.

Dry deposition is another mechanism for the transport of air contaminants to water. Freudenthal (1970) set up a model to measure dry deposition onto the surfaces of salt water under spray and non-spray conditions. He demonstrated that the scavenging fallout by a factor of two. However, since the percentage of surface that is actively producing spray is relatively minimal, according to Volchok (1972), the input of contaminants by this means is negligible relative to the total world ocean fallout.

Liss (1975) and Volchak (1975) have presented work relevant to the functioning of water bodies as sinks of various air pollutants as has Hutchinson and Viets (1969). Studies relating to emissions from water bodies (e.g. Bouldin et al. 1974) clearly indicate that water bodies are important but we were unable to gather sufficient relevant literature upon which to draw general conclusions. The literature seems fragmented and not sufficiently practical to be used to generate sink or emission factors in which we can have confidence.

* The following bibliography pertains to this Addendum.

Bachmann, John D., and Don Lokey. (1972) "Effect of air contaminants on water quality." Research Triangle Park, Pollutant Strategies Sec., North Carolina, 4p.

Bouldin, D.R., R.L. Johnson. C. Burda, and C.W. Kao. "Losses of inorganic nitrogen from aquatic systems." J. Environmental Quality, 3 (2): 107-114 (1974).

Freudenthal, P.C. "Aerosol scavenging by ocean spray." USAEC, Report HASL-223 (1970).

Hutchinson, G.L., and F.G. Viets, Jr. "Nitrogen enrichment of surface water by absorption of ammonia volatilized from cattle feedlots." Science, 166 (3904): 514-515 (1969).

Liss, P.S. "Gas transfer across natural air-water interfaces, with special reference to lake surfaces." Proceedings of the Second Federal Conference on the Great Lakes. (Prepared by Argonne National Lab. for the Interagency Committee on Marine Science and Engineering of the Federal Council for Science and Technology). Argonne, Illinois, pp. 248-254 (March 25-27) (1975).

Volchok, Herbert L. "Fallout upon open waters." Proceeding of the Second Federal Conference on the Great Lakes (Prepared by Argonne National Lab. for the Interagency Committee on Marine Science and Engineering of the Federal Council for Science and Technology) Argonne, Illinois, pp. 255-258 (March 25-27) (1975).